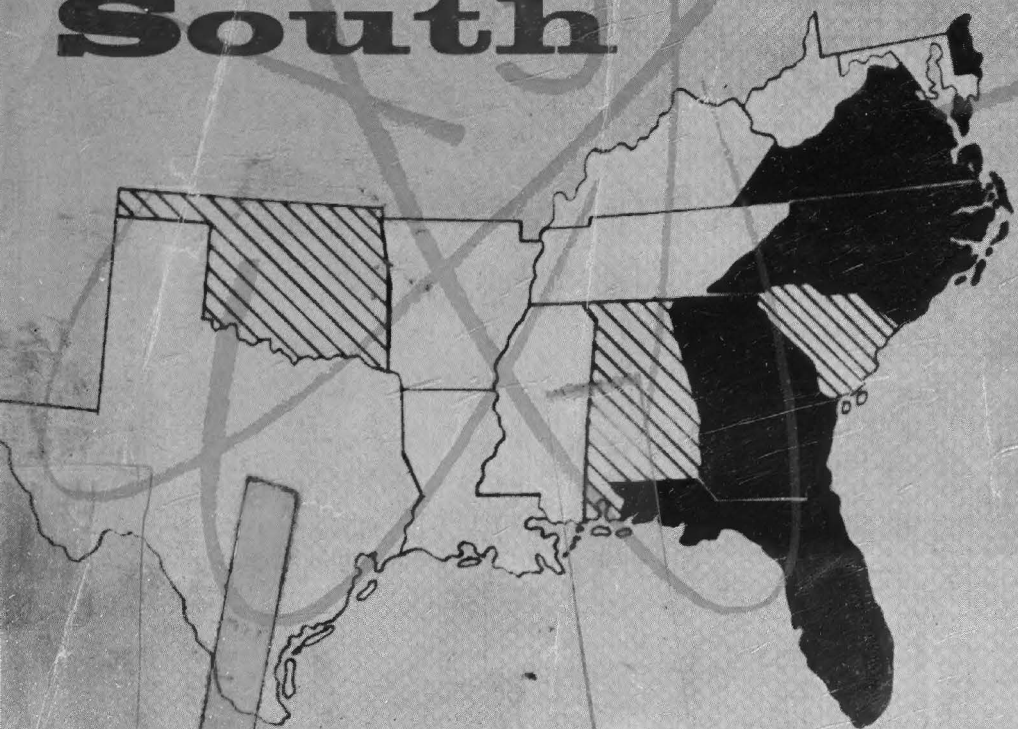


Redding Sugg, Jr.

Nuclear Energy in the South



NUCLEAR ENERGY IN THE SOUTH

Edited by REDDING SUGG, JR.

This book blueprints the coming Atomic Age in the South from the present until 1975. During this period the nation will enjoy a new phase of growth and power, one in which nuclear energy will transform industry, engineering and agriculture, and bring miraculous advances in medicine and public health.

Convinced that the economic future of the South lies at the heart of the atom, the Southern governors delegated the Southern Regional Education Board to prepare the present business-like study. Here based upon the most careful research and planning is a full prospectus of how the South can act now to achieve a dominant place in the national economy.

A major feature of the book is its striking plan for an interstate compact for nuclear development. This plan will go far to insure a united, successful program with a maximum of state, rather than federal, control. Valuable coverage is also given to a variety of nuclear projects of Southern industrial groups and to the thorny problem of educating scientists and technologists.

Men in education, government, business and industry, and all those interested in a more dynamic and prosperous South will find this book worthy of their closest attention. It reflects the work of many planning sessions, technical panels, and special studies sponsored by the Southern Regional Education Board, between its own consultants and experts from the professions, industries, universities, and government agencies. Southern and nationwide.

NUCLEAR ENERGY IN THE SOUTH

NUCLEAR ENERGY

Edited by

REDDING S. SUGG, JR.



IN THE SOUTH



Louisiana State University Press

BATON ROUGE



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Library of Congress Card Catalogue Number: 57-13162

Printed in the United States of America by
the William Byrd Press, Inc., Richmond, Va.

Designed by Jean Kyle & Associates: Pauline Manning

ACKNOWLEDGMENT



The technical and regional background papers on which this book is based were made possible by a grant by Resources for the Future, Incorporated, to the Southern Regional Education Board.

EDITOR'S PREFACE



This book goes to press as the governors of sixteen Southern states and their agents study the practicability of an interstate compact to promote nuclear industry on a regional scale. The Regional Advisory Council on Nuclear Energy, a creature of the Southern Governors' Conference,¹ is developing recommendations on the matter with the aid of the Southwestern Legal Foundation of Dallas. By the time this book is published, the governors will have held their 1957 meeting, at which these recommendations will be presented. The pace of events is such that the decision to draft and seek legislative ratification for an interstate compact may have been taken before these pages can reach the reader's hands.

In that case, the materials presented here should gain rather than lose interest because they represent the studies which have already led to the creation of the Advisory Council and which will underlie any further developments. In order to understand the forces in play, the reader must turn his attention to the 1955 meeting of the Southern Governors' Conference, at which the

¹ The states represented in the Southern Governors' Conference and in its Regional Advisory Council on Nuclear Energy are Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

issue of nuclear development was raised by Governor Collins of Florida.

Governor Collins argued then, as he has since argued on numerous occasions, that the South must exploit nuclear energy as vigorously as possible if the region is to maintain, much less improve, its industrial rank among the several regions of the nation. Traditionally industrial areas, such as New England, where scientific and technical talent is more plentiful than in the South, are looking to nucleonic development to compensate for deficiencies in power and labor. Governor Collins has argued that regional action will be necessary if the South is to do more than produce the raw materials from which nuclear energy may be created, and he has frequently reminded the region that industrial processing adds a greater increment of wealth than production of raw materials. Unless the Southern states act together to encourage nuclear industry, the governor predicts that it will develop in the present centers of industrial activity in the North and West to the virtual exclusion of the South.

Till recently, the United States Government has almost completely dominated nuclear science, technology, and industry in the name of national security. As initiative in the pacific uses of nuclear energy passes into private hands, many groups and agencies will be affected. State and municipal governments in particular have an exhilarating opportunity to exert themselves and thus to justify by works those "states' rights" which have been such a shibboleth. Because of federal policy, state governments have had little experience with nuclear development but now face the task of regulating nuclear enterprises in ways which serve the public interest without stifling industry and research.

Such considerations moved the Southern Governors' Conference to request the Southern Regional Education Board to organize a regionwide conference "to deal with the feasibility of united action in the development of industrial opportunities in the South through nuclear energy and research." The Board conducted a series of studies in preparation for what was called a Work Conference on Nuclear Energy, which was held at St. Petersburg, Florida, on August 1-4, 1956; and the present volume is largely a compilation of those studies. The Work Conference was a cross-section of the groups and institutions in the region

concerned with nuclear energy: agriculture, electric power companies, industries, the medical profession, state and municipal governments, and universities. Representatives of these groups discussed the materials in this volume and voted recommendations for presentation to the governors at their 1956 meeting.

Since the governors endorsed the recommendations of the Work Conference (with a single reservation which is reported on page 14), these should be taken as the governors' views wherever they appear in this book whether specifically credited to the governors or not. To state in every instance that a given recommendation by the Work Conference was endorsed by the governors would be tedious.

The chapters which follow range from carefully documented studies by individual authors to editorial syntheses of the work of several authors, committee reports, and stenographic notes. Most of the material which they summarize or reproduce may be found in the working papers mimeographed by the Southern Regional Education Board in two volumes entitled "Work Conference on Nuclear Energy, St. Petersburg, Florida, August 1-4, 1956." The first chapter deals with nuclear energy in relation to the production of electric power in the South. The next three are about the uses to which the by-products of nuclear fission—heat and radiation—may be put, and indeed are being put, in general industry, agriculture, and medicine and public health, with special reference to Southern conditions. Finally, trained manpower and the program required to supply it are presented as essential to any significant development of nuclear science and industry in the South. The recommendations which the governors endorsed in each of these fields appear at the conclusion of each chapter and thus make a somewhat arbitrary, but it is hoped a helpful, framework. Where individuals are responsible for chapters or sections of chapters, their contributions are noted.

The reader's indulgence is claimed for the inevitable unevenness of tone which characterizes such a compilation. Dr. H. D. Bruner's discussion of nuclear medicine, for example, which appears as part of Chapter IV, is extremely technical and therefore, for the general reader, unintelligible in certain passages. On the other hand, in Chapter II, for example, a much more summary and popular treatment was possible.

Such editorial problems aside, the book should give citizens at large an idea of the thinking which has already resulted in the important activities of the Regional Advisory Council on Nuclear Energy. This group comprises sixteen persons appointed by the governors as representatives of the states concerned plus seven others, chosen by the nucleus of sixteen, who represent professions and industries concerned with nuclear energy. Its chairman is Robert M. Cooper, director of the South Carolina State Development Board, and it operates through a staff located in Atlanta. Since its organization in February, 1957, as the result of one of the recommendations reported in this volume, the Council has established relations with such groups as the electric power companies, the U. S. Atomic Energy Commission, and the Joint Congressional Committee on Atomic Energy. It is available to help in removing obstacles to the orderly development of nuclear power and industry and in forwarding the increasing responsibilities of the states for inspection of nuclear facilities.

But above all, the Council is, at this writing, concerned with the study of the many legal, physical, and technical problems which must be identified and dealt with before an effective interstate compact to promote nuclear industry can be proposed. The pervasive impact of nuclear energy on government, health, education, industry, and the professions—and so, ultimately, on the general welfare—has led the Southern governors to suppose that interstate cooperation will be necessary if the new force is to be used to the greatest advantage. It would be difficult to cite, anywhere in the contemporary American scene, a grander enterprise.

R. S. S.

Atlanta, Georgia
July 19, 1957

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NUCLEAR ENERGY IN THE SOUTH

DEVELOPING NUCLEAR POWER
IN THE SOUTH

In seeking to organize their region for leadership in nuclear science and industry, the Southern governors are facing the problems posed by nuclear fission as a source of heat for the production of electric power. The nuclear power reactor is technically but not economically efficient. The heat which it produces can be used to make steam or to heat liquids which may then drive a turbine, which can, in turn, drive an electric generator or propel a ship or aircraft. Nobody doubts that the nuclear reactor will become a major source of energy, supplementing fossil fuels and hydro sources. By 1980, the United States will have installed 100 million kilowatts of nuclear-powered electric generating plants, representing 20 per cent of the total electric generating capacity and a capital investment of \$25 billion.¹ Foreign countries with less abundant fossil fuels and hydro sources may turn even more rapidly to nuclear power. The director of reactor development for the U. S. Atomic Energy Commission has recently stated that nuclear energy can be expected to become an important source of electric power during the next twenty-five years, both in this country and abroad, without reducing the demand for conventional fuels.²

¹ Michael Michaelis, "Profits from Nuclear Power," *Harvard Business Review*, XXXIV (September-October, 1956), 103.

² W. Kenneth Davis, "Role of Nuclear Power in Meeting Our Energy Needs," speech before National Coal Association, June 13, 1956.

Nevertheless, nuclear power is not yet economically competitive in the United States with power generated from coal, oil, gas, and water. The power industry is concerned not so much with competition in the production and sale of nuclear power as with reactor technology and related conditions such as government regulation and the availability of insurance for nuclear enterprises. A leading industrialist argues that "it is one of the basic characteristics of our economic system that, in the advancement of any technology, those concepts and designs which show promise for advances in efficiency or economy tend to be selected quickly. . . . There is every reason to believe that this process is working and will continue to work in the atomic power field." He adds that "the nation's best interests will be served by giving every encouragement to private industry and other non-federal interests to use their initiative and their resources to the fullest in the development of atomic power."³

The Atomic Energy Commission is also emphasizing technical development rather than immediate, large-scale production of electric power from reactors now available. The American policy runs contrary to the programs in the United Kingdom and in Russia, where the nuclear electric capacities projected for 1960 exceed the anticipated American capacity as of that date. With respect to numbers of reactors already built or projected by 1960, however, the United States leads not only these two countries, but these plus all others. "Our diversified reactor construction program," an internationally known authority on nuclear power has recently stated, "is aimed at a better understanding of the technical problems standing in the way of low cost nuclear power, rather than an attempt to win the race of 'nuclear kilowatts'." The development of low-cost fuel elements and of techniques for using liquid fuels suggests that nuclear power competitive under American conditions will become a reality.⁴

Competitive nuclear power may be expected to come in the South, as elsewhere in the nation, because the demand for energy is rapidly increasing while the supply of conventional fuels is

³ Philip Sporn, President, American Gas and Electric Company, testimony before Joint Committee on Atomic Energy, U. S. Congress, May 25, 1956.

⁴ J. A. Lane, "The Status of Reactors and Developments in Reactor Technology," paper before American Nuclear Society, June 6-8, 1956.

decreasing. Most of the sixteen Southern states have, however, relatively low-cost power, an abundance of cheap fuels, and well-developed hydro power resources. The immediate prospects for nuclear power seem less promising in the South than in other regions, such as New England, where conventional power is more expensive. A spokesman for major Southern power interests puts the situation thus, "There is not under construction or under design today a nuclear reactor which will compete economically with conventional fossil-fuel-fired plants. The low cost of fossil fuels in many parts of the South makes those areas less likely as immediate locations for economically competitive nuclear plants than other areas where conventional fuels cost more."⁵ He agrees, therefore, with another power company executive's belief "that the most beneficial thing the states can do, insofar as nuclear power development is concerned, is to assure a favorable regulatory climate for the utility companies . . . the spending of research and development dollars is necessary to make nuclear power competitive. It is vitally important that state regulatory commissions recognize this by permitting electric utilities under their jurisdiction to expend a reasonable number of such dollars each year and to treat such outlays as normal operating expenses for rate-making purposes."⁶

Like the private power companies, the Tennessee Valley Authority is looking ahead to the installation of nuclear power plants within the next two decades. Although a number of undeveloped hydro sites remain in the Tennessee and Cumberland basins, TVA studies indicate that most of them are economically marginal. The amounts of energy and capacity potentially available from them are small in comparison with projected system requirements. TVA feels that relatively little account need be taken of contributions from new hydro sources in its area, and nuclear sources will therefore be welcome.

TVA is assuming that nuclear power plants will ultimately be more economical than coal-burning plants in its area. Meanwhile it expects an extended period when the two sources of energy

⁵ H. J. Scholz, President, Southern Services, Inc., statement to Southern Regional Education Board.

⁶ Statement from a Mississippi power company executive to Southern Regional Education Board.

will compete with each other. It expects to install its first nuclear unit by the beginning of this period, which is not likely to come on the TVA system before 1965. The load growth by that time may reach a rate of about 1,300 megawatts a year; by 1975 it may be about 3,000 megawatts a year. If the superiority of nuclear units has been established by 1975, additions to the TVA system would be nuclear units. These would probably be of the largest available size. Assuming "normal" reliability, TVA thinks that individual reactors large enough to produce 1,000 megawatts electrical output might be feasible on its system by about 1975.⁷

THE SOUTHERN MARKET AND NUCLEAR POWER

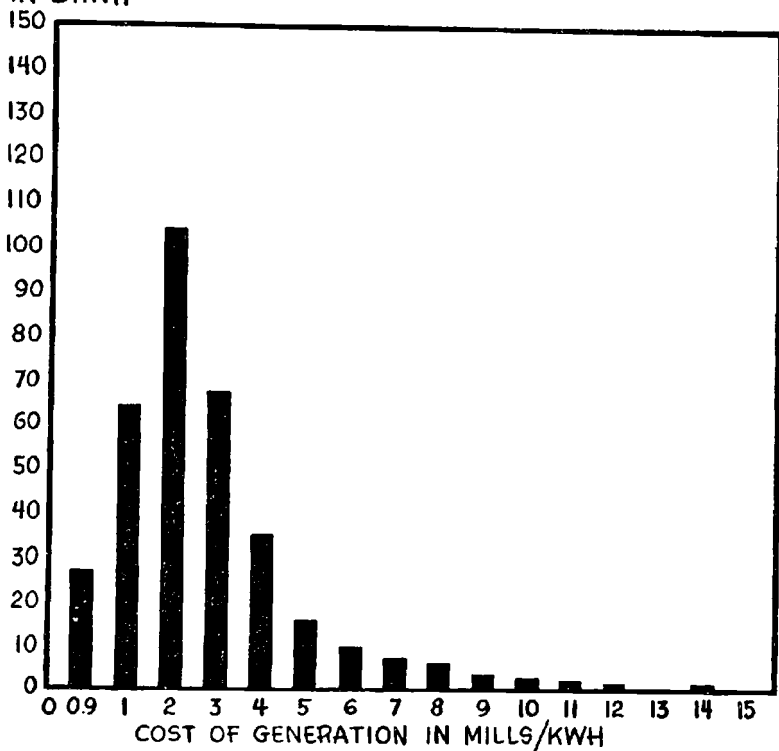
Although technical and economic conditions may delay the advent of nuclear power in the South, detailed consideration of the Southern power market reveals some interesting exceptions among the states and suggests that considerations other than the question of profits from nuclear power may affect the situation. Dr. Karl M. Mayer of the Stanford Research Institute prepared a report for the SREB Work Conference on Nuclear Energy which contains a review of the Southern market on which he based a projection of the potential impact of nuclear power.⁸ The Mayer report covers the sixteen Southern states for the period 1956-75 and involves a study of future production and consumption of power and the competition between nuclear and conventional sources.

According to the Mayer report, the amount of power consumed in the South will probably grow by a factor of three between 1954 and 1975. The relative positions of individual states in the production of electric energy may shift markedly. The relative importance of such states as Florida and Arkansas will probably increase while that of Maryland, for instance, may decline, although total production for the region will increase. Utility-produced

⁷ These views paraphrased from a statement to Southern Regional Education Board by Tennessee Valley Authority.

⁸ Cf. Karl M. Mayer, "The Size and Nature of the Southern Market for Nuclear Power," working papers of the SREB Work Conference on Nuclear Energy, mimeographed August, 1956, Vol. I, 12-54.

FIGURE 1:

*THE MARKET FOR NUCLEAR POWER IN
SIXTEEN SOUTHERN STATES FOR 1965*NUCLEAR POTENTIAL
IN BKWH

power and steam-electric generation will probably rise in importance.

The report includes calculations of the size of the market for nuclear power for each of the states concerned as of 1960, 1965, 1970, and 1975. These calculations take into account competition with each prime mover at generating costs from 0 to 15 mills per kilowatt hour at the bus bar (that is, at the generating plant). The market in 1965, for instance, would be about 45 billion kilo-

watt hours at 6 mills; 30 billion kilowatt hours at 7 mills; and 20 billion kilowatt hours at 8 mills. Total production of electric power in the South is expected to be more than 300 billion kilowatt hours by 1965. The share of the market held by nuclear power in that year will be largely at the expense of planned fossil-fuel steam-electric plants.

The Southern market for nuclear power will not, according to the Mayer report, be as great as the national market because of the relative abundance of low-cost power sources in the region. The indicated market for nuclear power in the South varies widely, however, from state to state. Nuclear power may be expected to have a major impact in such states as Florida, Georgia, North Carolina, and Virginia, while such states as Mississippi, Louisiana, and Kentucky will experience much smaller impacts or none at all in the years ahead. The greater the distance from conventional energy sources, the sooner nuclear energy may be expected to come into significant play.

About 6 per cent of the power produced in the South in 1975 will probably come from nuclear plants if generating costs are substantially reduced in the meantime. The fortunes of nuclear power will vary, of course, as future conditions vary from those postulated. If the costs of fossil fuel should rise unexpectedly, the position of nuclear power will improve; if conventional power technology advances, the position of nuclear power will probably decline. On the whole, however, the Mayer report confirms the opinions already quoted to the effect that there will be little if any economic need for nuclear power in the South in the years immediately ahead.

It may be remarked here that the Mayer report professed to be only the beginning of an effort to answer a series of very complex questions. As an overall treatment of the market for nuclear power in a broad region, it might well be supplemented by local studies of power consumption. A series of local or state studies would lead to more precise projections for certain parts of the region than could be made on a uniform basis in the regional study. Although the uniform, straight-line projection method produces useful if rough approximations of growth in power consumption for most of the states concerned, the projections for some states are doubtful. In Tennessee, for example, the large

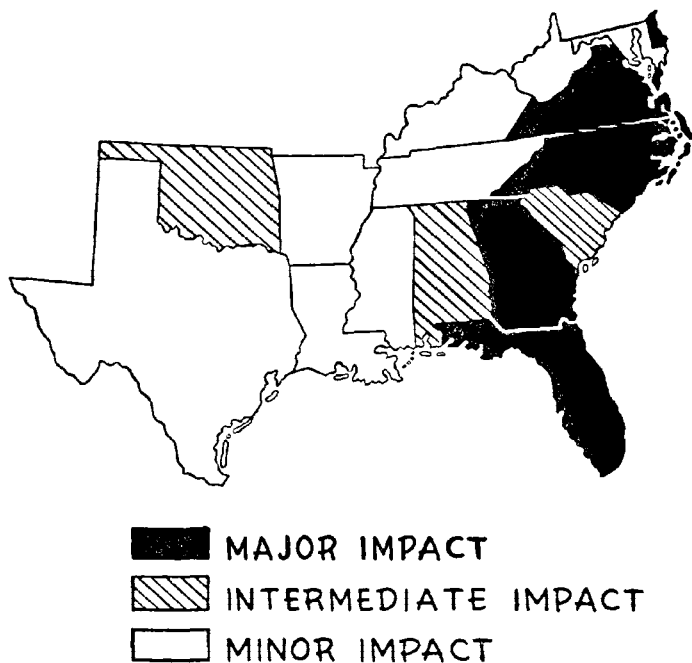
Atomic Energy Commission load growth caused a distortion which made it difficult to project the total growth. Even major adjustments in the projected Tennessee load, however, would not significantly alter the broad conclusions presented in the report.

Production analyses complementing a coordinated series of local power consumption studies might also be undertaken with advantage. Detailed projections of specific industry and local power load growth should be combined with projections of the manner in which future loads will be covered. These studies would involve projections of power technology under specific circumstances and deal with such problems as the forecasting of fuel costs for plants not yet designed. Projections of power technology should be a part of an overall economic study of future consumption and production of power. In this fashion it would be possible to project more precisely the future competitive position of nuclear power and the impact of nuclear energy on the power economy, on individual states, and on the fuel economies of the South.

Since there is little immediate need, in terms of the market, for nuclear power in the South, development of nuclear reactors, essential not only as a source of energy for electric power but as a basic element in general industry after 1975, would have to be subsidized. The Mayer report indicates that if nuclear power plants should be built in the South for non-economic reasons, they would probably require least subsidy in the states on the Eastern seaboard. The Power Demonstration Reactor Program of the Atomic Energy Commission, which is being financed jointly by government and business, will result in seven plants with between 800,000 and 1,000,000 kilowatts of electric-power capacity by 1962 at a total cost of some \$350 million. The Commission is trying to hasten the production of nuclear power within the United States and to shift initiative from government to private enterprise by making federal funds available to private utilities which incur greater expense in developing nuclear plants than they would in operating a conventional one.

The question of subsidizing demonstration power reactors is especially interesting in the South, where nuclear power may not become competitive until after it has entered the market in other regions. The South's concern is intensified by the probability that

FIGURE 2:
ANALYSIS OF POTENTIAL IMPACT OF
NUCLEAR POWER IN THE SOUTH, 1965



the presence of nuclear power industry might, as the Mayer report suggests, inspire enough general economic activity to justify payment of a subsidy by shareholders, ratepayers, or taxpayers of the region. The further possibility that tax payers in the country at large might pay the necessary subsidy must also be considered.

In the meantime, many power companies operating in the

South are active in nuclear power development. According to a statement from Southern Services, Inc., the companies with which it is affiliated have been active for several years. The companies in question include the Alabama, Georgia, Gulf, and Mississippi Power Companies and the Southern Company. They have contributed money and personnel to the Dow Chemical-Detroit Edison nuclear power study group and to Atomic Power Development Associates, Inc., which replaced it. Some fifty officers and employees have been given access permits to classified material by the Atomic Energy Commission.

The Southern Company system also participates with a group of utility and industrial companies headed by the Detroit Edison Company in building and operating a 100,000 kilowatt nuclear power plant in Michigan under the AEC reactor demonstration program. This reactor, which will be of the fast breeder type—that is, it will produce as much nuclear fuel as it consumes—is expected to cost about \$40 million, of which the Southern companies will contribute about \$2 million in addition to guaranteeing \$500,000 of the debt of the plant.

The Florida Nuclear Power Group, comprised of the Florida Power Corporation, the Florida Power and Light Company, the Tampa Electric Company, the Allis-Chalmers Manufacturing Company, and the Babcock and Wilcox Company, was recently formed to build and operate a large nuclear power plant in Florida. Various types of reactors, including the bismuth-graphite reactor, are being considered.

The executives of the Southern power companies which participated in the SREB Work Conference on Nuclear Energy prepared suggestions for action aimed at developing nuclear power in the region. Of prime importance, in their opinion, is "educational work to inform industry as to the industrial opportunities connected with nuclear energy." They think that the states and various industries should promote public forums to make correct information about nuclear energy generally available. States and the region as a whole should provide information, probably through existing channels, on meteorological, geological, hydrological, and other conditions of special interest to nuclear industry. Information about legal, economic, and industrial conditions should be available in the same places.

The power company executives were concerned that the region's colleges and universities, and the secondary systems on which they depend, should be given the support necessary for them to carry out research and train men for nuclear engineering and industry. Cooperative ventures among industries and between industry and the states should be undertaken to insure thorough investigation and application of nuclear energy. State universities should install, they feel, small research reactors and related equipment needed to train Southerners for positions in the industry and to undertake research on local problems. The power company executives also advocated scholarship programs, planned to improve elementary and high school teaching as well as to develop undergraduate and graduate college education in mathematics, science, and engineering. They think that duplication of effort and investment should be avoided wherever possible and that existing facilities such as the Oak Ridge National Laboratory should be fully exploited.

The executives recommended the development of uniform laws, codes, and regulations throughout the region in order to provide a clear framework within which industrial planners might work. Joint development programs among states or between states and industries should be started. From the point of view of the private power industry, then, popularization of information about nuclear energy and its applications, development of nuclear research and training, and the clarification of government regulations are the paramount objectives at this time.

PROPOSED REGIONAL AND STATE ACTION

The SREB Work Conference on Nuclear Energy, taking into consideration the suggestions just outlined, formulated four recommendations of its own to the Southern Governors' Conference with respect to the development of nuclear power in the region. The first is based on the conclusion that what is needed today is the design of more efficient reactors rather than the construction of any sizeable number of uneconomic reactors. The Work Conference recommended "that the states within the region continue

to rely on the existing power systems and manufacturers for the orderly economic development of commercial nuclear power in the South in order to bring the benefits of lower power costs, at the earliest possible time, to the consumers within the region."

The second recommendation asked "that the Southern governors take action toward enabling institutions of higher education to train a larger number of engineers and scientists, who are vitally needed to further the advancement of nuclear power in the South." The rate of development of nuclear power and of industrial, medical, and agricultural uses of nuclear by-products will depend in large part on the availability of professional and technical manpower. Nuclear techniques provide powerful new research tools and increase the kinds of problems which can be effectively attacked. The results create demands for many scientists and engineers for work not only in nuclear projects but in other areas as well. The SREB Work Conference argued that unless a major educational effort is begun at once, the industrial development of the region will be seriously handicapped for lack of personnel.

The Work Conference recommended further "that the individual states promulgate appropriate regulations and/or legislation consistent with developments in nuclear technology as related to nuclear power which will protect the public health, safety, and welfare, and that such regulations be reasonable in the light of furthering rather than restricting nuclear development, and be applied uniformly and without discrimination within the state." The regulations called for here should be based, the Work Conference declared, on detailed analyses of radiation safety codes, licensing regulations for nuclear plants, building codes, and the requirements of nuclear waste disposal. Regulations should not be drafted in haste, since there is in many instances little experience on which to base them. The Work Conference suggested that advisory committees on atomic energy be organized in the several states to develop specific regulations which would provide a realistic situation for the increasing use of nuclear energy. Many regulations bearing on the safety, health, and welfare aspects of nuclear energy may be identical in several states or indeed throughout the region. The U. S. Bureau of Standards, the National Committee for Radiation Protection, and

the American Standards Association, among other groups, have established standards for the guidance of local agencies.

Finally, the SREB Work Conference recommended "that the governor of each state alert the insurance commissioner and the [proposed] state advisory committee on atomic energy⁹ to keep abreast of progress made by the federal government on insurance covering nuclear reactor installations." Under present conditions, radioactive fallout resulting from an accident at a reactor could bring on damage claims far beyond the means of both the operator and the insurance companies. Unless insurance against liability for such damage is made available, the financial risk involved in nuclear installations will deter if not completely block the early development of nuclear power generation, not only in the South but in other regions as well. A federal insurance statute will probably be enacted. At least for the present, federal policy with respect to insurance for nuclear reactors is paramount, and the states will probably have to adapt their own policies accordingly.

In adopting the recommendations of the SREB Work Conference, the Southern Governors' Conference felt that those relating to nuclear power were acceptable for the time being. The governors, realizing that the situation may change rapidly as the U. S. Atomic Energy Commission declassifies information and as reactor technology advances, thought that the time was not ripe for flat conclusions. They went on record as believing that technical developments leading to the economic production of electric power from nuclear fission "should be observed closely," and that the governors "should be alert to the possible need for special counsel in this field to provide continuing review and appraisal" of progress toward nuclear power for the region.

⁹ Most of the Southern governors have appointed such committees, the chairmen of which become members of the Regional Advisory Council on Nuclear Energy.

NUCLEAR ENERGY AND INDUSTRY IN THE SOUTH¹



In the South as elsewhere, nuclear reactors will probably be used most generally to produce heat for the generation of electricity, but other types of reactors produce heat and radiation that can be used in many other industrial processes. The heat may be used in space heating and in propulsion of ships, aircraft, and locomotives. In addition, the radioactive substances which occur as by-products of nuclear fission will be increasingly important in many types of manufacturing and processing. The manufacture and sale of reactors, in which competition is already intense, may play a part in the future American economy comparable to that of the automobile industry during the past several decades. As the rubber and oil industries, for example, developed in conjunction with the manufacture of automobiles, great new industries may rise with the manufacture of reactors. Nuclear industry in all its manifestations will doubtless develop where conditions are favorable, and Southern leaders are organizing to provide these conditions in spite of the fact that the immediate market for nuclear electric power is small.

It should be emphasized that "nuclear industry," in common

¹ The material for Chapter II was compiled largely by R. Maxil Ballinger, general advisor and consultant for the SREB Work Conference on Nuclear Energy; James J. Dutton, formerly Managing Editor, *Nucleonics*; and Seymour Henck, manager of the Work Conference.

usage, refers to all production, processing, and related professional and service activities based on nuclear energy *except* the production of nuclear power. The components of nuclear industry include, first, the industrial concerns which are doing work, much of it highly classified, under contract with the U. S. Atomic Energy Commission. Another group includes firms which use the several products of nuclear fission: power is the best known, but radiation may prove more important. A third and perhaps ultimately the largest group consists of subcontractors who supply the goods and services which nuclear operations require. Within a few years, a fourth group made up of users of large quantities of heat, such as the paper and pulp industry, may figure importantly in nuclear industry. Persons who provide indirect services, such as financing, legal advice, and insurance, form yet another component. And the community at large, whether represented by state and municipal governments, by development boards, or by committees combining business, government, and education (such as those advocated by the Southern Governors' Conference), makes a sixth category.²

A full-fledged nuclear industry would affect almost all segments of business and industrial life. Sales of nuclear power plant equipment and components alone may amount to more than a billion dollars during the period 1955-63, and this estimate excludes the possible demand for similar components in propulsion or research reactors and for other radiation and research facilities. Nor does it include possible overseas sales, which have been suggested as a source of profits and experience for American manufacturers of reactors during the years ahead when nuclear power will be uneconomical in this country.³

OPPORTUNITIES FOR NUCLEAR INDUSTRY

Heat and radiation are the products of nuclear reactors on which industrial development will be based. The following sec-

² Cf. Eugene M. Zuckert, "How a Manufacturing Company Enters the Atomic Energy Field," *Prospects for Atomic Energy in the South* (Atomic Industrial Forum, Inc., 1956), 109.

³ Cf. Michaelis, "Profits from Nuclear Power," *loc. cit.*, 99-115.

tions review some opportunities for nuclear enterprises under these headings. In addition, activities already under way in the South are cited.

Nuclear Heat

Propulsion of land, sea, and air vehicles; space heating; and economic process heating (the use of heat in processes of production) are the chief applications of the heat which may be derived from reactors.

Nuclear propulsion of ships is far advanced. The submarine *Nautilus* has been at sea for nearly two years, a second nuclear submarine has been launched, and the U. S. Navy is constructing others. Naval architects and engineers are also designing surface vessels which reactors will propel. Meanwhile, the U. S. Maritime Administration is encouraging the construction of reactors to propel merchant ships.

The U. S. Air Force is rushing the development of nuclear aircraft. It has not solved the problem of carrying reactors and their heavy shielding in the comparatively small space available in airplanes, but success may be expected within a few years. Although they will probably develop later than the nuclear ships and aircraft, nuclear locomotives are in prospect, too.

These developments in nuclear propulsion imply a great variety of opportunities for private nuclear industry. Marine nuclear propulsion requires the design and construction of ships adapted to new conditions, the design and construction of appropriate reactors, the manufacture of boilers and heat-exchangers, the fabrication of fuel, instrumentation, decontamination services, and the disposal of atomic wastes. Although most of these activities will be government prime and subcontract work and limited as to profits by price redetermination and renegotiation, the important circumstance is that they permit alert firms to move onto the ground floor of nuclear industry and, in effect, be paid for learning the business.

Several firms with Southern plants are prime contractors in marine nuclear propulsion. Among them are Babcock and Wilcox Company, Lynchburg, Virginia; Newport News Shipbuilding and

Drydock Company, Newport News, Virginia; and the Ingalls Shipbuilding Corporation, Pascagoula, Mississippi. Subcontractors are an increasingly significant element as they supply equipment and engineering to cope with the complexities of the equipment and the stringency of the requirements of any nuclear-propulsion system. A growing number of Southern companies are doing this kind of work. Both prime and sub-contractors are enjoying benefits which are only indirectly related to the nuclear side of shipbuilding. They are expanding and adapting existing lines of products and developing new ones, and in the process they improve skills and manufacturing techniques.

Although for some time to come private industry will find its greatest opportunities in connection with the Navy's program of nuclear development, Southern firms are already active as prime contractors in aircraft nuclear propulsion. For example, Convair has a nuclear development plant at Fort Worth, Texas; Lockheed has facilities at Dawsonville, Georgia; and the Glenn L. Martin Company participates in the Navy's nuclear plane program at a plant near Baltimore.

Heat from nuclear reactors, like heat from any other source, may also be used for space heating, as it is at the nuclear research establishments at Harwell, in the United Kingdom, and at the AEC Hanford Works in the state of Washington. The reactors are not competitive with conventional heat sources, but space heating from nuclear reactors may eventually become economic at least for central heating systems supplying a complex of buildings and for private users in heavily populated areas. Because the South has such a brief cold season, nuclear space heating would seem to have less future there than in most regions.

Southern industry may find the reactor more interesting as a source of process heat. Certainly the paper and pulp industry, which is a major element in the industrial economy of the region and which consumes large quantities of process heat, should investigate the possibilities. The importance of sources of process heat may be illuminated by the fact that about 12 per cent of the nation's total energy production is consumed in producing metals, chemicals, cement, glass, paper, petroleum, and rubber products. As this is written, reactors produce process heat limited to temperatures ranging from 1,500 degrees F. to 3,000 degrees F., but re-

actors will probably be developed to produce economic process heat at lower temperatures within the near future.

Nuclear Radiation

Radiation, the single new resource created by reactors, may also become significant in industry. Its applications have yet to be extensively explored. It is, however, extremely valuable as a tool for chemist, metallurgist, scientist, and engineer. Possible uses of radiation in manufacturing are suggested in the following statement by Bernard Manowitz, Chief of the Fission Product Utilization Project of Brookhaven National Laboratory:

The advent of nuclear power will not only amplify the electrical power resources of this country, it will also create a supply of by-product radiation power. The fact that there will be an assured supply of this new mode of power has stirred a lot of interest in its possible uses. . . . Conventionally heat has been used to energize molecules for chemical reactions, to destroy bacteria for sterilization purposes and the like. Radiation is another way of adding energy to a system. From a chemical point of view, it can produce free radicals where you want them, and at any ambient temperature in the system. . . . The one thing we can say about new uses . . . is that these are bound to increase as more ingenious experimenters turn their attention this way.

There are two general ways in which radiation can be used to induce chemical reactions. Radiation can be used to trigger a chemical chain reaction; that is, there are certain chemical reactions in which radiation can supply a small amount of energy to start a reaction, and chemical energy will carry the reaction the rest of the way. And there are reactions in which radiation must supply all of the energy for the entire reaction.

An example of the first or chemical chain reaction type is polymerization. This is the process by which plastics are made. Practically every polymer of the addition type that can be initiated by a free radical can be prepared by a radiation technique. This would include the preparation of polyethylene, polystyrene, polymethyl methacrylate, butyl rubber, GRS, polyvinyl chloride, polyacrylonitrile, polyvinyl acetate, and many others of our large tonnage plastics.

Another field of interest is that of vulcanizing and curing elastomers and plastomers. Recent work at the Wright Air Development Center and at the Goodyear Company has indicated

that rubber can be vulcanized by radiation. It is unlikely that this technique can be applied to tires because of the awkward geometries involved, but radiation vulcanization may be applicable to belting and other rubber products which are adaptable to continuous processing, provided radiation can be supplied cheaply enough.

Let us now consider some chemical reactions where radiation must supply most of the energy for the reaction. I am thinking now of the possibilities of producing heavy organic chemicals by a radiation technique. There are some research results on phenol, hydrogen peroxide, aniline, glycols and hydrazine production. Not only U. S. investigators, but also the Russians seem to have done a considerable amount of work in this direction. Most of this work is characterized by low yields so that probably reactors would have to be used as a very large source of radiation.

A considerable number of Southern chemical and petroleum companies are purchasing facilities to develop means of using radiation to induce chemical reactions. Specialty products will probably be the first to be economically processed on a broad scale.

Since agriculture in all its aspects is relatively important in the South, the sterilization and preservation of food by radiation is of immediate interest to the region. This use of radiation could markedly affect consumer patterns, packaging, shipping procedures, marketing, and food processing. Commercial applications of radiation to preserve food are imminent and will develop probably in this order: potatoes, drugs, beer, meat, grain, packaged food, and dairy products.⁴ The Army Quartermaster Corps is already using nuclear facilities to irradiate foods.

RADIOISOTOPES IN INDUSTRY⁵

Only since the advent of the nuclear reactor has it been possible to produce radioisotopes on a large scale and to use their

⁴ "Where Does Food and Drug Processing Stand?" (Radiation Sterilization: No. 11), *Nucleonics*, XIII (January, 1955), 36.

⁵ The information on the use of radioisotopes in Southern industry presented in this section is summarized from responses to questionnaires sent by the Southern Regional Education Board to about one thousand firms in the sixteen Southern states during the summer of 1956.

radiations for a significant variety of industrial purposes. Some fourteen hundred industrial uses of radioisotopes have been developed in the United States. Most of these have to do with quality control and production efficiency, with the result that radioisotopes are credited with saving industry as much as a hundred million dollars annually. Such savings may increase to a billion dollars annually within a decade.

A "radioisotope" is a radioactive isotope, while isotopes are the several varieties of any given element, having the same chemical properties but different masses. Some isotopes are stable, or non-radioactive, but others are unstable, or radioactive. These—the radioisotopes—emit three kinds of rays, known as alpha, beta, and gamma rays, which differ in their capacity to penetrate and can be used accordingly. Some isotopes are naturally radioactive but too rare and costly for general industrial uses. Artificial radioisotopes, however, are produced by reactors; the principal production unit in this country is at Oak Ridge, Tennessee.

Industry uses radioisotopes in a great variety of ways, both in production operations and in research. As substitutes for radium or X-rays, they have proven economic. They are also valuable in gaging the thickness of coatings and materials, and they serve as "tracers": when mixed with the stable atoms of a given substance, radioisotopes signal their presence by radiation and so trace the movements of the substance in question through the most complex processes. In addition, radioisotopes are used to locate objects; to measure wear, oxidation, and corrosion; to determine flow; to determine components in mixtures; to improve methods of radiography; to discharge static electricity; and to improve radiation gages.

Radioisotopes in Production

In the South, radioisotopes are being profitably used in metal-fabrication, cigarette, paper, plastics, rubber, petroleum, and chemical industries. For example, the metal-fabrication firms which cooperated in the studies preliminary to the SREB Work Conference on Nuclear Energy have found it economical to substitute radioisotopes for X-ray machines in checking the safety

and reliability of their products. Radioisotopes do the same job, yet they are cheaper, do not require electric current, can be moved about more easily, and act faster if sufficiently radioactive. One of these firms reported that the use of cobalt-60, which is a radioisotope, "saves us about \$150 per month over a radium source." A shipyard reported even larger savings, stating that within ten months "our cobalt-60 source has saved us \$8,000 over previous methods." Other firms using cobalt-60, cesium-137, or iridium-192—all of which are radioisotopes—informed the Southern Regional Education Board that, although results were difficult to evaluate, certain benefits had been realized. Among these were safer and higher-quality products, greater customer confidence, improved production methods, reduced capital investment, and early discovery of flaws which saved machining time.

Other Southern industries are using radioisotopes primarily to gage and control the thickness of materials. They can do so because of the circumstance that the rays emitted by a radioisotope become less intense the further they travel through a material. Thus a measure of the radiation coming through a sheet or rod of material moving on a manufacturing machine tells how thick the material is. Cigarette manufacturers are now using beta radiation gages to measure rod-thickness so accurately that the daily mean weight of cigarettes is controlled to 0.2 per cent—half that obtained by the most careful manual control.

In addition to cigarette manufacturers, producers of paper, metal sheets, rubber, and plastics are using beta gages to control thickness. Absolutely uniform calendered vinyl sheeting, for instance, is now produced with the aid of beta gages. They have brought about great improvement in the control of yarn and twine coatings, and they make possible uniform thickness in paper which is essential in standardizing quality and in maintaining high-speed production. A Southern paper mill executive summed up opinion on thickness gaging by radiation in commenting, "While we have no figures on actual savings achieved through use of the gage, we feel that the difference in our operations is like working with the lights off and on. We now know what is happening every moment."

The measuring and control of density by use of radioisotopes are also becoming invaluable in industry. Density gages depend

on the fact that the heavier or denser a liquid, the less radiation passes through it. They make it possible to measure the composition, height, or location of liquids or slurries in the operations of many petroleum and chemical companies. Density measurements permit continuous blending of various fluids so that rapid production of controlled mixtures is possible. One Southern chemical firm which uses density gages informed the Southern Regional Education Board, "Quality has been improved and net savings in the past three years are over one million dollars." Another firm reported that liquid-level measurement with a density gage "eliminates the necessity of physically gaging petroleum tanks and saves operating costs." Where access to a vessel of chemical fluids was difficult with conventional float-type level controllers, a saving of about five thousand dollars was realized by still another Southern chemical company.

Related to density gages are the flow gages, which are useful in detecting the interface when a fluid of different density replaces a fluid in a pipe. A Southern oil company reported that it saved about two thousand dollars in installation costs by using a gamma gage rather than a mechanical system for detecting a pipeline interface. Between six hundred and eight hundred gamma-ray gages are in use throughout the United States in industries ranging from pharmaceuticals and glass to food and petroleum. The development of increasingly sensitive and at the same time more durable instruments and reductions in the price of radioisotopes are leading to even wider use of gamma gages.⁶

The use of radioisotopes as tracers is most noteworthy in the production of oil. The radioactive materials allow producers to follow the flow in underground pipelines, to find the placement of acid so as to dissolve limestone most effectively and increase production of oil and gas, and to check water flooding. Another use of tracers was reported to the Southern Regional Education Board by a manufacturer of electric blankets who uses phosphorus-32 in blanket-wire fabrication. He can save material because the tracer enables him to locate accurately and automatically certain sections within the finished wire.

⁶ P. E. Ohmart, "Radiation Measures Density," *Nucleonics*, XIV (May, 1956), 62.

Radioisotopes in Research

The use of radioisotopes in production operations has already done much to improve and standardize the quality of specific products; their use in research is tremendously important for advances in the future. Radioisotopes are used in research mostly because of their characteristics as tracers, although they are also important in radiography, in the development of radiation gages, and in the establishment of routine uses of radiation to induce various chemical reactions. In almost any industry, radioactive tracers are used in several distinct ways for research purposes. Tracers are valuable in determining locations; in measuring wear, oxidation, and corrosion; in determining flow; and in determining the behavior of the components of mixtures.

The use of radioactive tracers to determine locations may be illustrated by the practice of mounting a radioisotope on a mechanism for cleaning the inside wall of a pipeline. The tracer gives off radiation by which the device can be located. The location of an obstruction inside a pipe may be determined by inserting a radioisotope and following it till it is blocked.

Wear, oxidation, and corrosion may be measured more accurately by use of radioisotopes than by other methods. For instance, in testing a system designed to rotate piston rings during operation so as to assure even wear, it was formerly difficult to determine the rotation rate of the installed rings. By putting a small amount of gamma-emitting isotope on a point in the ring, the rotation rate may now be found by counting the times the radiation source passes a detector mounted outside the cylinder.⁷ It is possible to measure the effect of generator load on the erosion of a turbine wheel by coating the wheel with paint containing a small amount of arsenic-76 and measuring the change of radiation level outside the machine.

Radioactive tracers also help in determining wear of dies, electrical contacts, gears, engines, tires, and plastic molds. A plastic mold erosion test may be made in about thirty minutes with radioisotopes as compared to about three weeks with any

⁷ G. D. Calkins, "Radioisotopes—Versatile Research Tools," *Nucleonics*, XIV (May, 1956), 42.

other method. Furthermore, it has been estimated that industry in the United States could save at least a billion dollars annually by applying tool-wear radiotracer studies to machining operations.

Radioisotopes have also made it easier and cheaper to run full-scale studies of flow, the third of the types of research mentioned above. For instance, ten dollars worth of beta-emitting tritium may be diluted with fifty thousand barrels of hydrocarbon and still be detected accurately; and a gamma-emitter, also costing about ten dollars, may be detected accurately in six hundred thousand barrels of liquid. A typical large oil refinery handles about one hundred thousand barrels of crude oil each day.

The inexpensive radioisotope techniques allow oil companies to improve refinery processes through flow studies. One Southern oil company, for example, reported using radioisotopes to measure flow of liquids through refining equipment, to determine pattern of flooding profiles in secondary recovery operations, to locate fractures hydraulically produced to stimulate production, to trace the fluids used in fracturing, to dispose of several materials used in treating oil wells, to follow gas migration in underground gas storages, and to measure the amount of catalyst circulating in various parts of fluid units. In most cases, the results were not obtainable by any other practicable method.

As for determining the behavior of components of mixtures, radioisotope techniques have been very effective in more than one type of industry. A cigarette manufacturer, for example, reported to the Southern Regional Education Board the use of tobacco "labelled" with carbon-14 to determine the absorption and elimination by the human body of components in tobacco smoke. These studies are to be supplemented by use of a tritium-labelled compound. The detoxification of nicotine has also been studied by such means. Another instance was reported by a chemical company: "We are currently using radiocesium in research for measuring the amount of liquid entrainment from a solution being distilled. Information obtained by counting the activity of product samples and of areas in the equipment has been most helpful in determining optimum conditions and equipment for minimizing entrainment of liquid in this operation."

Furthermore, the basic mechanisms of mixing, a phenomenon of importance in many industries, may be studied much more

readily with radioactive tracers than with any other technique. The tracers help determine the best mixing time and conditions for producing such items as metallic alloys, plastics, paper, cosmetics, detergents, mixed foods, gasoline, oil, greases, waxes, paints, and cements. For instance, a Southern aluminum firm reported plans to use radioisotopes in an effort to determine how alloying elements affect corrosion and mechanical properties, and many chemical manufacturers use radioactive molecules to follow the mechanism of complex organic chemical reactions.

In radiography, many companies in the South are using gamma radiation, which is similar to X-rays, to detect flaws in many types of mechanical products. Such research leads to cheaper and more effective procedures for making castings and welds, for example. One Southern shipbuilding firm reported using radioisotopes radiographically in developing procedures for welding thick materials, and a metal fabrication firm pointed out that routine use of radioisotopes for radiography allows better design analysis.

Research designed to hasten the development of radiation gages has been aided by radioisotope techniques. Many firms are still not able to use radioisotopes routinely in their research, analytical process control, and production operations for lack of suitable instrumentation; hence, the urgency of research on gages and the importance of radioisotopes in this connection. One instrument firm reported that its research department uses radioisotopes in developing new types of radiation-level controllers and specific-gravity indicators. Several manufacturers of nuclear and mechanical equipment are using isotopes in their development programs, planning, for instance, to extend the use of automatic control equipment using radioisotopes to all appropriate industries in the South.

Radiation is also used in research for static electricity discharge, for quantitative analysis of materials, for standards, and for nuclear batteries. Ionization produced by radiation from radioisotopes provides a way to eliminate a charge of static electricity without touching the charged material. This technique is valuable in situations where an expensive but sensitive material is produced on a machine in which a charge is built up. In quantitative analysis, radiation is used to detect extremely small amounts of impurities in various materials. Many chemical, oil,

metals, and tobacco companies in the South use radioisotopes for this purpose. A Southern petroleum firm, for example, uses radioactive materials in logging oil wells: a neutron-emitter is lowered into a well long enough to irradiate a certain region; then a radiation detector is lowered to measure the hydrogen concentration in the formation by the amount and type of induced radioactivity. A tobacco-products company—for another example—has helped to finance an industrial research reactor. One of the uses the company will make of it is to determine trace elements in tobacco by neutron activation analysis.

A number of instrument companies and research groups in the South are using radioactive materials as standards. One research firm reported to the Southern Regional Education Board the effective use of such materials as light-source and voltage-source standards. They are also used as sources in low-brightness photometers, according to a report from an instrument company.

Problems in the Use of Radioisotopes

Most of the companies which reported use of radioisotopes to the Southern Regional Education Board stated that they encounter no more problems here than they do in introducing any other new tool into their operations and research. In general, problems have arisen in regard to techniques, costs, and employee-relations, the latter including safety and training in the use of radioisotopes. The majority of radioisotope users in the South have relied on the manufacturers of radiation equipment to set up their equipment and give them technical guidance. Since the equipment manufacturers are usually familiar with application, most problems are solved easily. Where the application is new and no commercial experience has been accumulated, or when a company decides to set up its own equipment without benefit of outside experience, more difficult problems must be surmounted.

New applications usually present most of the cost problems. Costs of instruments and equipment, however, are bound to come down as more units are installed and accuracy is improved. Costs of isotopes are also certain to fall as more reactors and isotope-processing plants come into operation.

Radiography, probably the most entrenched of radiation applications, is relatively trouble-free. Firms which are extending the technology, however, have to refine their techniques. A foundry reported that it was hampered by lack of technical data on radiographing thicknesses greater than six inches, but it is overcoming the difficulty by experimentation. An electrical-equipment manufacturer was troubled because a flaw could be so small that the isotope he was using would not reveal it although it was large enough to be detrimental to the product operation. Better interpretation of the film solved the problem. An aircraft builder in the South is having trouble expanding his uses of radiography because available isotopes are somewhat limited. A shipbuilder reported that installation costs are relatively low; the chief problem is that of handling costs. This involves special leadlined carrying cases, hand magnets on extended reach rods, and mechanical devices which crank out flexible cables. Most radiographers agree with the shipbuilder about cost.

Beta gages for measuring thicknesses have, by and large, been trouble-free too. Most equipment is serviced or checked periodically by the instrument maker. A cigarette firm stated, "The only difficulties were faulty electronic tubes which were used initially. This condition has been corrected and the equipment is operating satisfactorily and with a minimum of maintenance." Nearly all the Southern paper mills reported no difficulties with their beta gages; one stated, however, that investment is high, amounting to tens of thousands of dollars, that equipment deliveries have been very slow, but that there are few maintenance problems.

A plastics firm operating in the South reported that installation cost is high, about ten thousand dollars per unit, but that there are no maintenance problems. One cigarette company, however, has had maintenance trouble. The company reports, "Installation costs are high and maintenance is constant and costly."

Gamma gages for measuring fluid densities and levels are regarded by Southern users as similar to beta gages as far as technical and cost criteria are concerned. Although most Southern chemical and oil companies rely on the gage manufacturers to service and adjust their equipment, many call on their regular electronic-instrument technicians to maintain the gages. Some

petroleum users have reworked commercial equipment to improve it. Many firms believe cost to be high, though justifiable in light of results. One chemical company cuts cost by "judicious purchase from several manufacturers on the basis of recommendations of our research staff; our own construction of some basic accessories has also lowered equipment costs." Most users agree with a Southern oil company's report that the device is so simple in design and operation and requires so little adjustment that no special technical personnel have been required. That there are, nevertheless, limitations on present use of gamma gages is attested by a pipeline firm whose tests on a radioactive gravitometer on a 24-inch crude oil line showed it to be impractical, probably because of the large fluid column diameter.

Southern companies report that tracer applications of radioisotopes are quite straightforward in the hands of trained personnel. None of the firms surveyed by the Southern Regional Education Board reported any major problems. "The difficulty of obtaining isotopes of convenient half-lives" was, however, a problem to a chemical company—half-life being the time required for radioactive material to reduce its original amount of radioactivity by half. Excessive government red tape disturbed a research and development firm, but other groups praised AEC regulations, recommendations, and assistance as guides to sound and safe practices. Lack of adequate notice of changes in shipping and postal regulations, however, has hampered a research institute producing tagged compounds.

An appliance manufacturer stated, "We feel that the cost of our installation was somewhat excessive due to the lack of commercially available instrumentation for industrial application in connection with manufacturing processes." This executive summed up the opinions expressed by other Southern users, however, in saying, "The problems encountered do not differ in size or scope from those encountered in the development of other types of specialized processes." Most users emphasized staff training as being a necessary chore.

All Southern companies using radioisotopes have followed AEC recommendations and have had few safety problems. Companies following AEC recommendations, assigning responsibility to supervisors, and developing adequate indoctrination programs

have forestalled employee-relations problems. A few Southern firms that apparently did not give sufficient attention to indoctrination at the outset reported that they have had employees demanding premium pay rates which the companies believe excessive.

Steps taken to insure safety by Southern firms using radioactive materials include careful selection of personnel, comprehensive training programs, supervision to enforce safety regulations, radiation warning signs and safety ropes, heavy cement block walls around work areas, periodic monitoring for radioactivity, requiring personnel handling radioisotopes to wear film badges which are checked weekly and pocket dosimeters which are checked daily, special techniques for remote handling of isotopes, and having personnel take periodic physical examinations. Cooperating firms state that not all of these precautions are needed for every application. For instance, thickness and density gages for routine production use are usually in sealed units and require no special safety provisions. Careful design and adherence to AEC suggestions on construction, installation, and operation have prevented accidents.

Some firms have had trouble because radiological safety rules are not yet generally understood. A manufacturer of radiography equipment described such a problem as follows: "We have had difficulties in getting prospective customers qualified for licensing by AEC. Usually, this involves training men in the safe handling and use of multi-curie sources. The lack of readily available, low-cost training courses has made it necessary for us to develop our own 5-day training courses. We believe there is a definite need for elementary courses on radiological safety at various locations throughout the United States."

BARRIERS TO NUCLEAR DEVELOPMENT

Executives of the Southern industrial firms cooperating in the SREB project listed several "roadblocks" or limiting factors in the development of industrial applications of nuclear energy in

the South. Most of them cited as a major problem their lack of information on what is going on and little understanding of the business and economic opportunities that atomic energy offers. They felt that security regulations prevent many firms from getting the information they need to understand and evaluate industrial opportunities. (The shortage of trained manpower is generally regarded as an even more serious obstacle. This is a problem not only for the South, though perhaps it is more urgent and pressing for this region, but for the entire nation. The question of manning a nuclear industry and the related problems of education are treated in detail, it may be noted, in the last chapter of this book. The Southern industrialists also felt that public misunderstanding of nuclear energy and its uses is a major obstacle.

They advocated an aggressive public information program in the South. The first objective would be to popularize information about atomic energy, its potential benefits, and its uses for peaceful purposes. (The public should also be given the facts concerning safety and hazards of nuclear installations, in order to prevent exaggerated fears. The industrialists thought that such a public information program should make the public aware of the citizen's responsibility to foster laws and regulations which would safeguard the public health and interest, yet not unduly restrict nuclear development. The proposed public information program would stress the citizen's responsibility and interest in helping meet the manpower and educational needs of the atomic age and his right to be informed about a vast new field that he has underwritten with more than fourteen billion dollars in taxes.

There are two further considerations which, although they do not yet represent obstacles to the development of nuclear industry in the South, must be taken into account, the industrialists declared, if trouble is to be avoided in the future. They hoped that everything possible will be done to prevent the enactment of unduly restrictive laws and regulations by the several states. Their interest in public information is explained in large part by this concern. They also pointed out that as the uses of nuclear energy increase, not only in industry but in agriculture and medicine as well, the need for research will intensify. Rapid development of nuclear industry implies generous support for research

centers throughout the region in order that nuclear arts and science may be widely disseminated and brought to bear on particular problems and opportunities.

PROPOSED REGIONAL AND STATE ACTION

The SREB Work Conference concluded that the primary need of the region was for a research program which would prepare the way for nuclear industry. It noted that present facilities for nuclear industrial development are so inadequate that the demand for the services of test facilities will probably far exceed the capacity of all that might be built within the next ten years. Adequate nuclear test facilities would provide the greatest attraction for new industry and serve as a means for improving the competitive position of industries already located in the South. The SREB Work Conference felt that the region badly needs materials and engineering test reactors; chemical processing plants for reprocessing and reclaiming spent fuel element materials; and facilities for agricultural and biological research and for the production, processing, and application of radioisotopes.

Accordingly, the Work Conference recommended that "a long-range regional program be adopted to establish one or more strategically located nuclear test facilities in the South." The Conference thought that these facilities should be suitable for carrying on industrial work in nuclear technology. They should have a minimal operating staff but should be equipped sufficiently well to permit private industry to use them to their full capacity. The Conference further suggested that a 16-state board of directors be appointed to supervise the test program and that a suitable administrative agency be established as well. The Regional Advisory Council on Nuclear Energy requested, in July, 1957, bids from several nuclear engineering firms as a basis for determining the feasibility of building the desired test facilities.

The Work Conference agreed with the Southern industrialists who participated in the SREB studies that a regional program should be set up "to disseminate to Southern industry informa-

tion on actual experience and potential benefits of nuclear technology." It also recommended that regional conferences of industrialists be held to discuss and review industrial applications of nuclear energy. The Conference felt that too much information, rather than too little, is available, and that more material is being declassified, or made available on rather simple terms, by the Atomic Energy Commission than industry can readily assimilate. The chief need is for a system of evaluation and codification of material so that it may be easily applied.

As for the broader aspects of public information, the Work Conference thought that they should be left to the individual governors. The general public throughout the several states is poorly informed about the possibilities for regional development through the use of nuclear energy and about the opportunities for careers in nuclear science and engineering. It is probable also that a great deal of misinformation, especially about the hazards of using nuclear energy, is abroad and should be corrected. The Work Conference hoped that the several governors would sponsor broad programs of public information on these heads in their states.

NUCLEAR RADIATION IN AGRICULTURE



The increasing value of radioisotopes in the production and research activities of industry has already suggested that these by-products of nuclear fission may prove more important than the electricity which may be produced by reactors. Since radioactive materials may be introduced into living as well as into mechanical systems, their most significant uses may occur in the investigation of life processes of plants and animals. The tracer properties of radioisotopes permit study of processes such as photosynthesis in plants and digestion in animals which have remained mysterious till now. As the functions of organisms are understood, the causes of health and disease are clarified and more intelligent action to encourage the one and to prevent the other becomes possible. The applications of nuclear energy, in the form of radiation, in agriculture, medicine, and public health are therefore of the greatest interest. The SREB Work Conference and the Southern governors have placed at least as much emphasis on development here as on nuclear power and industry.

The principal contribution of nuclear energy in agriculture has been fundamental knowledge of the life processes of crops and livestock. By substituting labeled or tagged elements for some of the stable elements entering into plant or animal nutrition, it is possible to learn how an element is utilized by a plant or animal, how quickly the element enters into metabolism, and

what its final disposition is. The following statement sums up the matter:

The value of radioisotopes in agriculture arises from the ease and accuracy with which they can be identified and measured in extremely minute amounts, which makes it possible to use them as highly refined research tools in so-called tracer studies in a wide range of nutritional, metabolic, developmental, and pathological investigations in plants, animals, and man. In this way they are giving information which, at the present time, could be obtained in no other way or only at much greater expense in terms of time and money. Thus, by giving a clearer insight into basic biological processes that have hitherto been obscure, the use of radioisotopes in tracer studies is already leading to greater efficiency and economy in the production and utilization of agricultural products.¹

Agricultural research workers have been quick to take up this new tool and to use it with productive results. All of the agricultural experiment stations in the South are using isotopes in some way. Dr. Byron T. Shaw, of the Agricultural Research Service of the United States Department of Agriculture, reported as follows regarding the rapidity with which research workers had taken up the use of radioisotopes by 1954: "Forty state agricultural experiment stations are working with isotopes at the present time, either individually or in cooperation with the Federal Department of Agriculture. More than 150 investigations that depend essentially on radioactive isotopes are under way. Among these are 35 dealing with soils and fertilizers, 29 with chemistry, and 16 with various aspects of animal husbandry. In addition to this extensive program being carried on by the States, the Department's Agricultural Research Service has a number of projects that involve the use of isotopes. . . ."²

Radioactive materials are as valuable in studying biological processes as microscopes are in learning about the intimate structure of plants or animals. No laboratory would consider for a moment doing without a microscope. Neither would any competent biochemist, plant or animal physiologist, or practically any agricultural research worker now think of setting up a lab-

¹ "Uses of Atomic Energy in Food and Agriculture," *Proceedings of the International Conference in Geneva* (New York: United Nations, 1955), XII, 11.

² *The Contribution of Atomic Energy to Agriculture* (Washington: Government Printing Office, 1954), 6.

oratory which was not equipped to use radioactive isotopes. It should be emphasized that the new techniques will be used for increasing fundamental knowledge about plants and animals and not by the farmer directly to increase yields or to produce healthier livestock. The knowledge gained by research workers will enable them, however, to advise farmers about their many problems and thus help them to farm more successfully. The McKinney Report remarks in this connection, "Benefits of atomic applications to farmers can be as real and as immediate as each individual wishes to make them. The cumulative impact will be an increase in the farmers' ability to specialize, diversify, and better deal with their traditional worst foes—weather, pests and diseases."³

AGRICULTURAL PROBLEMS OF THE SOUTH⁴

The importance of agriculture in the South makes it especially urgent to develop the use of radioisotopes in agricultural research aimed at solving the problems of farmers throughout the region. Agriculture is more important in the South than in the rest of the nation because of the greater percentage of people living on farms in the Southern states. In the South 25.6 per cent of the population lived on farms in 1950, as compared with 15.3 per cent for the entire nation. The cash receipts from crops constituted 16.2 per cent of the total income paid to individuals in the South in 1952. This compares with 12.8 per cent for the nation. Therefore, it is imperative that ways be found to increase efficiency in producing and marketing agricultural products and at the same time to maintain or improve the quality of the products offered to the customer. The use of radioactive isotopes and radi-

³ Panel on the Impact of the Peaceful Uses of Atomic Energy, *Peaceful Uses of Atomic Energy* (Washington: Government Printing Office, 1956), I, 4. This work will hereafter be referred to as *Peaceful Uses of Atomic Energy*. For the sake of brevity, the work is referred to in the text as the "McKinney Report."

⁴ With the discussion of Southern agricultural problems and possible applications of nuclear science presented here, cf. W. Ralph Singleton, "The Place of Agriculture in the South," working papers of the SREB Work Conference on Nuclear Energy, mimeographed August, 1956, Vol. I, 3-25.

ation in agricultural research will make it easier to acquire information needed to achieve these goals.

In order to assess in a general way the agricultural problems of the region which might be met by the use of nuclear energy, the Southern Regional Education Board queried the commissioners of agriculture and directors of the state agricultural experiment stations throughout the sixteen states at the outset of the nuclear energy study project in the spring of 1956. The agricultural commissioners and directors of state experiment stations listed the principal agricultural problems of their states. The listing is by no means complete, but it gives a very good indication of the problems facing Southern agricultural research workers, Southern farmers, and state authorities. Although several states have some specialized problems, for the most part, the region has common problems. As will be shown in some detail below, nuclear energy has already proved valuable in agricultural research bearing on these problems and promises even greater results.

The following lists summarize current agricultural problems as reported to the Southern Regional Education Board by the agricultural authorities in the region. Problems of a general nature include:

1. Water shortage and drought conditions.
2. Surplus population in agriculture relative to income opportunity.
3. The small farm problem: inability of small farmers to compete with large mechanized farms; need for machinery which the small farmer can afford to buy and operate on the family-type farm.
4. Acreage control programs limiting small farms to uneconomical operations and development of alternative enterprises for fuller use of land taken out of production of major crops because of control programs.
5. Development and greater use of forest lands.
6. Development and greater use of land for pasture and forages.
7. Conservation of agricultural resources, land, and water.
8. Assistance to low-income and part-time farmers.
9. Cost of production: need for improvement in production efficiency and reduction in disparity between production costs of different types of farms.
10. Marketing and transportation costs: production of many agricultural items is wide-spread and cost of consolidation

for sale and shipment is adding to the high cost of production by reducing the margin of profit to the farmers and increasing the cost to the consumer.

11. Marketing of surplus production.

The agricultural specialists cooperating in the SREB project also reported the following as some of the more specific projects which should be undertaken for the improvement of the agricultural economy of the South:

1. Determination and adaptation of sound and efficient cropping practices on different soil types.
2. Development of crop species, varieties or hybrids of efficient and high potential productivity.
3. Studies of mineral makeup of soils and of soil structure and tilth as they affect growth of plants and soil micro-organisms.
4. Determination of sound and efficient fertilization practices including quantities, methods of application, rates and ratios of different elements, and types of fertilizers such as dry mixtures, liquids or gases.
5. Evaluation of supplemental irrigation with consideration being given to drought probabilities, including frequency, intensity, and duration, in order to determine whether or not irrigation is economically feasible. Determination of water resources for irrigation is needed.
6. Handling of surplus production—what can be done to store crops without spoilage, other than present methods of drying, canning, and so forth?
7. Control of the sub-microscopic viruses that ravage many crops.
8. Determination of what a plant needs when it is deficient in one or more plant foods.
9. Chemical control of insects on forage and cereal crops, vegetable crops, fruits, and of insects attacking man and animals.
10. Development of varieties of plants with better disease resistance and/or quality and productivity.
11. Control of soil-inhabiting pathogens, both fungi and nematodes.
12. Development and selection of more suitable and safer fungicides for foliar application.
13. Irrigation of crops and solution of related economic and legal questions; development of crop varieties which use water more efficiently and of soil covering to prevent evaporation from surface.

14. Development of cropping systems to prevent erosion from uplands and deposition in lowlands.
15. Uses of waste land; development of swamp crops, fast-growing, useful trees for use on various marginal fields or odd corners.
16. Development of cropping systems, fruits, vegetables, and others that would help the small landowner or suburbanite supplement income.
17. Development of better understanding of the mechanisms involved in the utilization of nutrients by ruminants, the growing and management of forages better adapted to ruminant nutrition, the metabolic reactions involved in milk secretion, and the maintenance of high quality in dairy products during the period between production and consumption.

APPLICATIONS OF NUCLEAR ENERGY

The South is happily in a strategic position to take advantage of nuclear energy in attacking its agricultural problems. Oak Ridge National Laboratory, where most of the country's radioactive isotopes are produced, is located in the South. A large staff of trained personnel is available there to assist with problems of using radiation or isotopes. The University of Tennessee, the Atomic Energy Commission, and the agricultural experiment stations have joined in making available a facility for treating seeds and growing plants with radiation, which is located centrally to serve the whole Southern area.

In addition, several of the Southern states are obtaining nuclear reactors for research and training. One already exists in North Carolina, and reactors are planned in Florida, Virginia, and Georgia. Most of these should have facilities for treating plant material. Also in Virginia, at the Blandy Experimental Farm at Boyce, a cobalt-60 plant irradiator has been established. This is primarily a research tool for finding out more about the way in which radiation may be applied to growing plants, and about the sensitive stage in the life of the plant. It is perhaps the most efficient method for the production of progressive mutations. Although much has been learned through the use

of the only other radiation field in this country, which is at the Brookhaven National Laboratory, much remains to be ascertained. It has been suggested that other institutions in the South be encouraged to obtain such a radiation facility for obtaining more information regarding mutations. It is possible to secure and install such a machine for less than ten thousand dollars.⁵

It would seem advisable for several of the states in the region to obtain such units. More worthwhile research could be done if several institutions, ultimately at least one in each state, had a radiation source as an adjunct to their agricultural research facilities. The use of several radiation machines in different locations would contribute markedly to knowledge about radiation effects. One of the prime functions of an investigator, even in the applied field, is to add to the pool of knowledge from which all investigators can draw. So, in addition to any centralized facilities, there is a need for the different research workers to have access to a radiation source fairly close at hand.

The question of centralized research versus research at the individual experiment stations has been debated often. Research in agriculture is most fortunate in that it has a long tradition of excellent work carried out at individual experiment stations, both in the South and in other regions. Discussions to date with the agricultural specialists in the region reveal that, in their opinion, research with isotopes or radiation can best be carried on by expanding the work already under way at the separate institutions and experiment stations in the South, rather than by attempting to set up a central laboratory devoted exclusively to this type of research.

In actuality a central laboratory is now in operation at Oak Ridge. Here workers will continue to conduct fundamental research and work at the threshold of basic science, not only in agriculture, but also in other fields such as nuclear physics, fundamental particle research, and medicine. Much of this research would be prohibitively expensive for individual states and institutions to carry out. Also located at Oak Ridge is a center for instructing workers in the use of isotopes and radiation. Research workers in the South will undoubtedly continue to look

⁵ Cf. Otto A. Kuhl, W. Ralph Singleton, and Bernard Manowitz, "Cobalt-60 Field Irradiation Machine," *Nucleonics*, XIII (July, 1955), 42.

to Oak Ridge for leadership in nuclear research in agriculture, basic nuclear science, medicine, and other fields.

Oak Ridge, together with the University of Tennessee, has already demonstrated this leadership in agriculture. Within the past year a cooperative program in plant irradiation has been developed. The objectives of this program are to promote crop improvement and genetic research by providing a facility for the irradiation of seeds and growing plants, and to determine more effective ways to utilize radiation technique in crop improvement.

T. S. Osborne, the coordinator of this UT-AEC agricultural research program, has commented on it as follows:

It has been shown that ionizing radiations accelerate the mutation rate in plants. Plant breeders are interested in using irradiation techniques to induce variability in existing crop varieties. The cost of suitable radiation sources and the experience required for their proper use have limited this approach. If radiation sources were made available on a *regional* basis with proper supervision this technique would be more widely used and prove of value in crop improvement programs.

Radiation as a tool in plant breeding is not only promising but proven. With this method new types have been found in cereals, legumes, and certain vegetables. The mutants have contributed higher yields, earliness, stiffness of straw, alterations of height, disease resistance and increases of certain chemical constituents. Radiation does not cause events to happen which could not happen naturally; it greatly increases their rate of occurrence, hence their probability of appearing in a given time.

The earliest applications of irradiation techniques in plant breeding were made in Sweden, by Gustafson, who developed two crop varieties of commercial importance by this technique. More recently in the United States, Gregory at North Carolina, Frey at Iowa, Konzak and Singleton at the Brookhaven Laboratories have reported desirable mutations induced by radiation.

Certain crops such as cotton, crimson clover, vetch, and barley appear to lack certain desirable characters for which no source of germ plasm is available for hybridization. For such crops the use of radiation sources may be of value.

The University of Tennessee-A. E. C. Agricultural Experiment Station will employ a scientist to advise interested plant breeders of the southern agricultural experiment stations as to the type and time of irradiation of specific seeds or plants to be in charge of receipt, irradiation, and return of materials

submitted formally by cooperating stations, to keep appropriate records and assemble from the cooperating plant breeders records of mutations found in the irradiated materials.

A neutron source for seeds and a low intensity source for growing plants are now available. A high intensity gamma source is also contemplated for seeds.

Dr. Osborne has reported that the program began full-scale gamma and neutron irradiations on May 11, 1956, and that within a month, sixty-five separate samples had been processed for plant breeders in ten states and territories.

Responses from the states cooperating in the SREB Nuclear Energy Project reveal that all of the state agricultural experiment stations have work in progress which involves radiation. The responses quoted below are fairly typical. They indicate what is being done and what could be done if more funds, research workers, and facilities were available.

At the present time [according to one response] atomic energy is being used extensively in our plant breeding program toward the creation of variation within a particular plant crop and has developed some very promising results. To a lesser extent radioisotopes are being used in soil and fertilizer research programs and in animal nutrition work. If sufficient funds were available a great deal of additional work could be done in these areas. We would be especially interested in expanding the procedures that we are now using on certain plants into a number of other fields and horticultural crops.

Another response runs as follows:

We have one project under way in the field of plant pathology utilizing radioisotopes to investigate problems in plant diseases and irradiation to select better agricultural products. Another project which will begin in the fall [of 1956] concerns radioactive iodine (I-131) studies on thyroid secretion to evaluate heat tolerance in Jersey, Holstein, and Sindhi-Holstein crossbred cattle.

The following projects are definitely planned for the near future and can be carried out with facilities and funds which are expected to be available:

Plant Pathology Research—Tracer studies of the basic mechanism of action of agricultural chemicals—fungicides and nematocides.

Dairy Research—Dispersion of antibiotic in milk and effect on milk in mastitis cattle. Mode of action of antibiotic on

growth response in calves using a radioactive element on the molecule. Mode of action of penicillin in preventing bloat. *Veterinary Science Research*—Use of radioactive materials to treat carcinoma in eyes of cattle.

Poultry Research—Inorganic sulphur (S-32) and methionine interrelationship.

Zoology Research—Radiation studies of genetics and cytology of *Drosophila* and other insects. Metabolic effects of unsaturated C-labeled fatty acids and radioactive fluorine in studying sodium fluoro-acetate as a poison.

If funds were made available so that facilities would be available to carry out a successful agricultural research program, we would need: facilities designed to house a multi-curie source for the irradiation of large animals, plants and plant parts, and large quantities of seed. Such facilities should be mobile to allow treatment of soil and sod for possible control of noxious pests. This should include facilities for tracer work for large animals and poultry. The building should be in an area well removed from the main campus.

Projects which could be initiated provided the above funds and facilities were available are:

1. Studies on milk secretion, using labeled elements, amino acids, fatty acids, vitamins, trace minerals and so forth.
2. General biochemistry and physiology of nutrients (amino acids) for livestock and poultry.
3. Fertilizer studies to evaluate percentage utilized by plants and in turn by livestock and poultry.
4. Methods of analyses for following metabolism of compounds in nutrition: hormones, vitamins, minerals, and so forth.
5. Chemotherapeutic agents—their mode of action in eliminating disease and parasites in livestock and poultry.
6. Radiation of cottonseed or other seeds followed by screening to obtain disease-resistant strains.
7. Metabolism of semen for artificial insemination and effect on frozen semen.

Current work being done includes the use of tracer elements in fertilizer studies and the use of tagged larvae in the studying of livestock parasites. If funds should be available to use atomic energy developments in our agricultural problems, the following fields will be investigated:

1. Food preservation
2. Nutritional investigations of irradiated foods
3. Ruminant metabolism
4. Synthesis of milk

5. Physiological studies in dairying involving thyroid activity, volume of body fluids, and so forth.
6. Insect control
7. The study of tillage and fertilizers with tracer elements
8. Studies of the use of nuclear energy for space heating, cooling, and refrigeration
9. Development of proper use of atomic wastes
10. Studies in animal and plant breeding

REVIEW OF RESEARCH

As agricultural experiment stations and other agencies in the South initiate studies with radioisotopes to help farmers, live-stock producers, and dairymen overcome their problems, encouraging results of research are rapidly accumulating in other sections and throughout the world. Radiation is being used effectively in the study of plant and animal breeding, physiology, and nutrition; of soils and fertilizers and their relations; of the nutritional value, sterilization, preservation, and deinfestation of foodstuffs; of the control of weeds, insects, diseases; and of certain operations in agricultural engineering. A brief review of developments in these areas is given here in order to suggest concretely the kinds of opportunity which radioisotopes are opening to agricultural science.

The first demonstration that radiation can be used successfully in breeding superior types of plants occurred in Sweden. Following the demonstration by Stadler and Muller of the United States in the late 1920's that radiation would produce genetic changes in plants and animals, two Swedish investigators decided to see what could be done by the use of radiation to improve crop plants. They worked largely with cereals. In a series of experiments these workers, H. Nilsson-Ehle and A. Gustafson, demonstrated that it is possible to produce many types of cereals including some which actually out-yield the parental varieties over a number of years. They also induced plants which were resistant to diseases of various kinds. Today, farmers in Sweden are growing varieties of cereals developed through radiation breeding. No longer is the plant breeder limited to mutations that

occur naturally. He can make them occur. Hence, evolution can be accelerated.

One of the most comprehensive experiments in this country was carried out by W. C. Gregory of the North Carolina Experiment Station. Experimenting with peanuts, he developed superior-yielding types and types which were more disease resistant than the parents, as well as types more amenable to harvesting by machinery than the parental types. Some of his cost figures are interesting and illuminating. The actual irradiation of peanuts at Oak Ridge cost \$160. According to Dr. Gregory, since that investment he and his associates have spent approximately sixty thousand dollars in looking over the material and carrying out experiments. Radiation is not magic, in other words. It is a new tool with which the plant breeder can obtain greater results than before. The need for trained geneticists to do breeding is still great and will remain so in the South as elsewhere, however, because the work is necessarily long and complex.

Work with radiation has shown that it is possible to induce disease resistance almost at will in crop plants if large enough populations are studied. Resistance to stem rust and victorae blight in oats, for instance, has been produced by radiation. Resistance to the deadly 15B strain of wheat rust has been produced in the new variety of Lee wheat by the United States Department of Agriculture and the University of Minnesota. The Swedish workers also turned up several cases of induced disease resistance in plants. Work is being undertaken at the Blandy Farm in Virginia to develop resistance to blight in the almost extinct American chestnut.

In regard to disease resistance in plants, there is the possibility of studying host-parasite relationships by means of radiation. A scientist at the University of Minnesota has suggested the possibility of exposing the pathogens to radiation to determine the range over which they can mutate. If extreme and virulent types of pathogens can be induced by radiation, it may be possible to breed the host plant so as to achieve resistance to these extremely virulent types. Thus one might control such diseases as that caused by the rust fungus which keeps developing new races of pathogens, some of which are extremely virulent.

Another use for radiation in plant breeding is "tailoring"

crops to meet specific demands. Cereals with materially shortened straw can be produced by radiation. These are useful in areas of high fertilizer treatment since the shorter types do not lodge so severely as the taller types. Also strains of cereals have been developed which make better use of high nitrogen fertilizers than the parent strains. It is possible to produce strains of plants which mature earlier, and thus to extend the area over which they may be grown. Some of the mutant types of cereal do better than the parental strains in dry or extremely wet environments. Thus it may be possible to develop plants with the growth requirements suited to any particular environment. Such developments would be of obvious advantage to agriculture in the South.

Grain sorghums have all been converted to dwarf types so that they can be readily harvested with the combine. The dwarfs which entered into these sorghums were spontaneous mutants; however, if more dwarfs are needed, they can be readily induced by means of radiation. A number of dwarf and semi-dwarf types of corn have been induced. Some of the spontaneous short types of corn have given surprisingly high yields in comparison with the parental types. The time will probably come when the short types will yield as well as, or better than, the tall types, and they are much easier to handle.

Another crop which has yielded to the radiation breeding technique is the soybean, from which higher yielding strains have been developed. It may also be possible to breed soybeans for response to different lengths of day. Soybeans do not fruit in Florida because of the short day, but by extending the range of response to day length it may be possible to develop a soybean for Florida. Spineless castor beans have been produced by radiation. In cotton, radiation may produce strains with a longer staple than at present. Plants better adapted to mechanical picking are needed also, and radiation may produce these.

Several diseases are particularly destructive in tobacco. If radiation works in tobacco as it does in crops on which it has been tried, it seems likely that resistance to these diseases can be developed. Again, in pasture grasses radiation may be used to produce strains which will stand severe drought conditions and flourish whether nitrogen is plentiful or not.

It is also possible to produce mutations in flowering plants,

such as carnations, by growing them in a radiation area. Such changes seem permanent and can be propagated, so that a new variety is established immediately. It has been suggested that radiation be used more widely for producing changes in somatic tissue in addition to those induced in the germinal tissue. Another interesting effect of radiation is the development of self-fertility among some of the sterile fruit trees.

The use of radioisotopes to trace the movement of fertilizer from soil into plants has given new information about fertilizer utilization. The tagged elements can be traced into the plant and located at any time without killing the plant. One of the most useful of the isotopes in this regard is phosphorus-32, one of the earliest used in fertilizer studies. On soils which had been cropped for some time and which had a residual supply of phosphorus, it was found that plants take much of their phosphorus from the soil and not from new applications.

Plants can absorb appreciable quantities of nutrients through their leaves as well as through their roots, and radioactive isotopes have been used advantageously in determining what amount of applied fertilizer is absorbed. The efficiency of the fertilizer applied to the leaves is much greater than that of fertilizer absorbed through the roots, although the concentration on a leaf must remain fairly low. It has also been demonstrated through the use of isotopes that plants lose some of their nutrients in very heavy rainfall by the process of leaching. Hence, if a fertilizer element is highly critical it might be necessary, after a heavy rain, for a farmer to make an additional foliar application.

Nuclear energy has also had a large impact on research in soils. More than three hundred scientific papers dealing with the use of radioisotopes in soil and fertilizer research have been published in the United States and Western Europe. The findings have had a particular significance in the South because of the heavy use of lime and fertilizer in this region. Isotopic dilution experiments have also been performed to evaluate the effective concentrations of various fertilizers in soils, using plants as indicators. From the fraction of a given fertilizer element in plant tissue which comes from the labeled fertilizer, the effective level of that element in the soil may be calculated.

Another very interesting application of radioisotopes to soils

research has concerned the mapping of root systems. Labeled fertilizer, usually phosphate, is injected into soil zones at different distances from plants and at different depths. By studying the radioactivity of the plants at various times during the growing season, the distribution of the roots can be ascertained. This technique can be used to study the effects of soil moisture, soil compaction, and soil reaction and fertility on the activities of plant roots in different soil layers.

Radioactive isotopes have also been of great value in studying the reactions and movements of fertilizers in soils. Ordinary chemical procedures are not very useful in this regard because they do not distinguish between soil and fertilizer sources of a given element. The use of radioisotopes has made it possible to study mechanisms and rates of reaction between different forms of plant nutrients in soils. Valuable information about reactions of phosphate, potassium, calcium, and other fertilizer ions has been gained. Much more work will be needed in this area. Movement of fertilizers by leaching and by diffusion has also been studied with the aid of radioisotopes. Knowledge in this area, combined with information about root distribution and activity, will aid greatly in prescribing the most efficient liming and fertilizer practices. The efficiency of different tillage operations in mixing lime or fertilizer with soils has also been studied with the help of radioisotopes. Soils research using carbon-14 has yielded much new information about the decomposition of plant residues in soils and about the build-up or depletion of soil organic matter.

In addition, radiation has been used in the study of the physical properties of soils. Two areas of great promise are soil moisture measurement and soil density determination. Soil moisture in the field can be measured conveniently and accurately by determining slow neutron fluxes in the vicinity of a neutron source placed in the soil. The possibility of determining soil density by gamma particle absorption methods is also being investigated.

Consideration should be given to the possibility of using radiation in small animal breeding although at the present time it does not seem feasible for large animals. A radiation breeding project might well be encouraged with the rabbit or poultry as

the experimental animal. Some work of this kind is going on at the University of California, where egg production is being studied. Radioisotope tracers provide a wide approach to studies of sperm and egg metabolism, preservation, and evaluation. In the allied field of fetal development, isotopes have already provided a means of studying placental transfer and fetal utilization of feed components and compounds of maternal origin.

The use of radioisotopes has made possible many advances in animal physiology and nutrition. In fact, the use of radioisotopes gives promise of pervading almost all studies involving the use of feeds, including digestion, metabolism, formation of animal products, and reproduction. It is probably fair to say that every research establishment in the field of animal nutrition and physiology will have to equip itself with techniques and facilities for the use of radioisotopes if it is to maintain a productive existence in the future.

Problems which were not solved until radioisotopes were available include demonstration of the nutritional need of livestock for trace elements such as cobalt. The very small quantity of cobalt which is required by livestock prevented studies by usual biochemical techniques. With the advent of cobalt 56-57-58 and cobalt-60 it became possible to study the role of cobalt in animal nutrition and the influence of other elements upon the synthesis and utilization of vitamin B₁₂ (which contains cobalt), at normal levels of cobalt intake of as little as 0.04 part per million in the feed. Much of this pioneering work with cattle was carried out at the Florida Agricultural Experiment Station.

Until recently, it has been impossible to determine the digestibility of calcium or phosphorus in farm animals, since both of these minerals are absorbed and reexcreted in the gut. Some of the calcium and phosphorus passes from the feed directly to the feces, but much of it is absorbed and reexcreted into the gut before it appears in the feces. It has been practically impossible to differentiate these two, and therefore it has not been possible to give a correct appraisal of the availability of calcium and phosphorus in various animal feeds. The amount of calcium and phosphorus which is reexcreted into the gut has now been determined by injecting radioactive calcium or radioactive phosphorus into the bloodstream. By this method, it has been possible to establish

how much calcium and phosphorus from a given feed passes through the digestive tract without being absorbed, and thus an accurate measure of the availability of calcium and phosphorus in various feeds has been obtained. For example, it was shown by California research workers that, while the apparent digestibility of the phosphorus of alfalfa hay for lambs was only 22 per cent, the true digestibility was 91 per cent, thus demonstrating that alfalfa hay is an excellent source of phosphorus for ruminants.

In the field of rumen function and particularly rumen microbiology, isotopes have provided a tool without which much of the current knowledge of this important organ could not have been obtained. Examples include knowledge of the use of inorganic sulfur, the conversion of carbohydrates to fatty acids, the synthesis of amino acids, and the role of micronutrients in the nutrition of rumen microflora. For years it was known that a substance in the blood, beta hydroxybutyric acid, which is derived from the butyric acid produced in the rumen by bacteria, was used in large amounts by the udder of the lactating cow. Ten years of study failed to disclose the importance of this material in the formation of milk until it was tagged with radioactive carbon in experiments at the University of Maryland. Within a matter of weeks it was established that it is a major substance in the formation of milk fat, being the principal precursor (with acetate) of the short-chain fatty acids of milk fat which exert a major influence in controlling the percentage of fat in milk.

Many uses of radioactive materials in human medicine apply equally well in the field of animal nutrition and physiology, and most were initially developed with animals. These include, among others, blood volume and circulation studies, mineral exchange, blood serum protein partition, tumor localization and treatment, thyroid function evaluation, and tissue accumulation or redistribution of specific isotopes. Radioautographs, which are possible only because of the availability of radioisotopes, have provided a means of studying translocation of elements within an animal body, even to the localization of an element within a part of a single cell. Bone formation and metabolism, feather formation, and the origin of feather components, wool formation,

and liver metabolism are examples of fields in which knowledge has been tremendously advanced because of the technique of radioautography. In combination with paper chromatography, this technique has permitted the observation of intermediates in the biochemical system, as for example when liver or tumor tissue is incubated in a specific substrate. The isotope-labeled compounds separate on the paper chromatograph and are located by means of the radioautograph.

Work with radiation in foods and nutrition is still in the exploratory stage. An idea of the possibilities of this application of nuclear energy may be gained from the following statement published by the National Academy of Sciences:

A recent development in food technology, potentially of considerable and possibly dramatic significance, is the recognition of the fact that radiation can be used as a means of preserving certain foodstuffs or of lengthening shelf life, either unrefrigerated or refrigerated. The radiation source may be gamma rays or high energy electron beams. No radioactivity is induced in the irradiated material. Feeding experiments to date indicate that foods so irradiated will prove to be suitable and safe for consumption by man. Parasites in meat and meat products can be killed by exposure to penetrating radiation; and undesirable postharvest changes in plant products, such as the sprouting of potatoes, can be delayed.

The prime objective in radiation processing is to destroy microorganisms, or so greatly to reduce the microbial population (radiation pasteurization), that spoilage is long delayed. To accomplish this, very heavy radiation exposures are necessary because microorganisms are much less sensitive to radiation than are animals and higher plants. The food processor is particularly attracted by the fact that the radiation exposure can and should be carried out after packaging.

The acceptability of some radiation-sterilized foods is open to doubt because of the development of off-flavors, and changes in odor or in the texture of the tissues. Much of the developmental work in this field however has been of a rather empirical nature, and it is possible that through research means may be found to repress some of these undesirable changes.

Although the feasibility of radiation sterilization has been amply demonstrated, the economics of the various processes have not yet been established. This development has largely been financed by the military with the Army Quartermaster Corps as the primary agency involved, but there has been a broad basis of cooperation in industry and elsewhere, with

some technical guidance and evaluation by advisory committees of the National Academy of Sciences. Having in mind the magnitude and coherence of the current broad programs in this area the Committee was of the opinion that the potentialities of this use of radiation are being thoroughly explored and that the interests of the food consumer will be adequately protected. At a later date the Committee expects to review particularly the evidence of wholesomeness and acceptability of irradiated foods.⁶

Radioisotopes have also been effective for the study of the action of herbicides on plants. The leaching of a certain herbicide through the soil has been observed with the radioactive compound, for example. Studies of the persistence of herbicides in soils and of the manner in which they decompose have been greatly aided by the use of radioisotopes. Such studies have greatly increased the adequacy and precision of chemical analysis of residues of herbicides in soils. Despite the fact that various radiations can kill plants, it seems unlikely that radiations will have any direct application to weed control, other than to provide better tools for research. It may be possible with the aid of radiation, however, to develop new varieties of crop plants more resistant to herbicides, which would make such chemicals safer to use in routine agricultural production.

Furthermore, radioisotopes have proved useful in researches with insects. For instance, according to a recent authority:

The depth, location and lateral movement underground of wireworm larvae have been followed by the insertion of cobalt-60 wire in the body cavity, and wireworm beetles have been labeled by placing radium-226 under the wings. Malaria, house and rockpool mosquitoes, houseflies, fruit flies, root maggot flies and screwworm flies have been labeled usually by mixing phosphorus-32 or strontium-90 with the food of the larvae, resulting in the production of adults that could be distinguished by Geiger counting. Cockroaches and flesh flies have been injected with zirconium-95 so that they could be detected at a distance. In this manner entomological studies are practical on distribution from breeding sites, flight habits, dispersion, food relationship, food contamination, infestation pat-

⁶ "Report of Committee on Agriculture and Food Suppliers," *Biological Effects of Atomic Radiation—Summary Report* (Washington: National Academy of Sciences, 1956), 96.

terns, longevity in the field, disease transmission, predation and similar points of interest.⁷

Radioisotopes have also been helpful in various studies on the physiology of the insect, as for example, the measurement of body-fluid circulation and studies of insect nutrition.

The action of various insecticides has also been studied with the aid of radioisotopes; for example, the action of DDT upon cockroaches. Studies with the systemic insecticide Systox (trialkyl thiophosphate) have been made in Oklahoma to determine how the insecticide is transferred in the plant body.

One of the most dramatic results of research using radiation is the possibility of exterminating the screwworm fly which attacks cattle and other farm animals and causes considerable damage. The males are sterilized by irradiation from a cobalt-60 source and then released in the general population. Since the female screwworm fly mates only once in her lifetime, it is possible completely to eradicate the screwworm fly, as entomologists have demonstrated on the island of Curaçao. Whether this technique can be applied to other insects or in large areas is not known at present, but attempts are being made to do so in Florida. Investigators are at present busy rearing large numbers of male flies which can be sterilized and released over Florida, a much larger area than Curaçao.

Another form of insect control consists of de-infesting contaminated grain or other agricultural products by means of irradiation. Much less radiation is needed to kill insects in the larval and egg stages than in the pupal or adult stages; consequently, radiation is applied, if possible, before the pupal or adult stages are reached. It does comparatively little good, of course, to clean up a sample of wheat or tobacco and then to put the product back into warehouses or granaries where there is an opportunity for rapid re-infestation. Perhaps one function of radiation in controlling insects in agricultural products will be to stimulate education of warehouse people to provide clean warehouses for the treated material.

Many of the radioisotope techniques used to study weeds and

⁷ Cyril Comar, *Radioisotopes in Biology and Agriculture* (New York: McGraw-Hill Publishing Company, 1955), 3.

insects have been applied also to the study of diseases. Studies on the physiology of animals and plants have been greatly aided by the use of radioisotopes. They have also aided in understanding of disease situations, in terms of the physiology and nutrition of various bacteria and fungi, and in the study of infection and disease. As an example of the latter, bacteria labeled with phosphorus-32 have been used to determine the retention and initial distribution of air-borne microorganisms in studies of respiratory infection in mice.

In agricultural engineering, as in engineering in general, there are many applications for radioisotopes. One of the important applications is represented by devices to determine moisture content of soils and other substances, such as forage and stored grains. The best growth of sugar cane, for example, depends to a large extent upon moisture content of the soil before planting. Moisture testing devices using radioisotopes have been made and used for this purpose in Hawaii. Moisture testing apparatus can also be applied to problems dealing with forage, either in the field or as ensilage, or to the monitoring of stored grain in elevators. Still another device uses a radioisotope as one of the components in an instrument for checking soil moisture to determine the proper time for irrigation.

Of great economic importance to the wheat-producing regions of the Southwest is the loss occurring in stored grain, meal, and flour through infestation by insects. The Engineering Research Institute of the University of Michigan has designed a gamma radiation facility for the control of such insect infestation of beans and small grains. For this work, cooling reactor-fuel elements were used as the radiation source, and the total cost of installation and operation was found to be only a fraction of that now spent for fumigation. This procedure further reduces losses due to downgrading of grain resulting from insect damage.

Radiations from a nuclear reactor can be used to good advantage to activate various tillage tools and harvester parts for the determination of rates and sites of wear. Methods such as those used in other engineering research on wear studies and nondestructive testing can be equally well applied to farm tool wear problems. Autoradiography and gross radiography have an important place in agricultural engineering research as it relates

to wear studies, radiographing welds and castings, and similar engineering applications of the isotope techniques.

PROPOSED REGIONAL AND STATE ACTION

In its effort to encourage the application of nuclear energy to agricultural problems, the SREB Work Conference felt that the regional program already centered at Oak Ridge should be heartily supported and more widely used. It suggested that travel funds be provided for staff members of agricultural experiment stations and colleges to visit the Oak Ridge facilities and make arrangements to have plant materials irradiated. It also felt that it would be wise to provide additional funds for growing large numbers of plants in order to increase the likelihood of beneficial mutations within a short time. In these ways it should be possible to develop disease-resistant and high-yielding varieties of cotton, corn, tobacco, pasture grasses, and other crops of economic importance in the region.

To complement the regional effort, the SREB Work Conference recommended that activities be stepped up in the several states. It felt that the governors might support provisions for training agricultural research workers in the applications of nuclear energy. A liberal leave policy for the staff members of educational institutions who wish to take advantage of training opportunities, involving only time, travel, and subsistence allowances, would probably accomplish more in bringing nuclear energy to bear on agricultural problems than the expenditure of larger sums in other ways. The Work Conference also recommended that the governors support agricultural research organizations and universities in making provisions for buildings, equipment, and personnel needed to make full use of radioisotopes.

NUCLEAR RADIATION IN MEDICINE AND PUBLIC HEALTH



Through the applications of nuclear energy in medicine and public health the South has a fresh opportunity for direct solution of its own health problems and development of its research and educational resources. Although a limited amount of work with nuclear energy in medicine and public health is being carried out in the several Southern states, the region as a whole is not keeping pace with activities elsewhere. It is generally conceded that the causes are apathy, both in the public and in professional groups; inadequate training programs and facilities in nuclear medicine; inadequate financial support of existing programs and a consequent lack of expansion and planning; and ignorance of what nuclear energy is and of what its benefits and hazards may be.

An idea of the uses to which nuclear energy is being put in medicine may be gained from the following summary, by a commissioner of health, of activities in one of the Southern states. He says:

A number of radioactive materials have been utilized in this state by the medical profession as a diagnostic aid and as a means of treatment. Iodine-131, phosphorus-32, gold-198, strontium-90 and cobalt-60, being used for treatment of thyroid disorders, cancer, and pericarditis, are examples. Our Medical Research Foundation has been using carbon-14, gold-198,

iron-50, iodine-131, phosphorus-32 and potassium-42 in animal studies of cancer, metabolism, tumors and hormone decomposition. The state universities have concentrated their activities in plant and animal studies, such as treatment, tracing of carbon dioxide absorption and effects of irradiation on biological materials. For this work they have used such radioactive isotopes as iodine-131, carbon-14, hydrogen-3, sulfur-35, strontium-90 and phosphorus-32.

In addition to the work being done by the above, we have a number of industries and individuals who are using radioisotopes either commercially or in research programs. The radioisotopes are used in subsurface geophysical measurements, fluid flow measurements, thickness gauges, well logging, radiography of materials, wearing tests and many others. Our particular interest lies in seeing that the individual is protected from harmful exposures and that proper disposal is made of the radioactive wastes.

The extension of the uses of nuclear energy in medicine and public health depends on the development of knowledge and techniques and an adequate supply of trained personnel. The medical and health problems of the South are not so characteristic as to distinguish them from those of the country at large, and the life sciences from which new solutions may be hoped are in no sense regional. Although the market for nuclear power, the region's stake in further industrialization, and the peculiarities of Southern agriculture and its relative importance economically may give a regional color to nuclear developments in other fields, work in medicine and public health must be part of national and international efforts. The SREB Work Conference, as its recommendations presented at the end of this chapter show, was primarily concerned to promote teaching and research and the rapid application of discoveries in nuclear science. The conclusions of the Work Conference are based on the reviews of the functions of nuclear energy in medicine and public health which follow.

PART ONE

MEDICAL APPLICATIONS OF NUCLEAR ENERGY¹

The term "nuclear medicine" is now established in the health sciences. A major radiological journal has incorporated it into its official title, and in 1956 at Salt Lake City a Society for Nuclear Medicine was organized. As of June 1, 1956, 1,318 physicians and medical institutions had been accredited to procure radioisotopes, compared to 1,363 industrial firms; these figures come to 40.2 per cent and 41.6 per cent, respectively, of the total 3,279 licensees. These figures demonstrate medicine's vigorous concern with the potentialities of radioisotopes. Work centering around the use of radioisotopes for therapy, usually against cancer, has received the most publicity, but as much work has gone into studying diagnostic and other practical medical applications of nuclear energy. An impressive literature has built up, which in terms of results shows remarkable consistency, although different individuals, possibly as an expression of their philosophy, interpret these data in different colors. All seem to recognize the radioactive isotope as a tool which will accomplish as many advances in medicine as the microscope.

The past ten years have been a period of exciting research freedom, but researchers are now on the verge of realigning their outlook in this field. In 1946 a rich stockpile of basic biological data was available which clearly marked off those procedures and experiments most likely to yield immediate practical benefits. This exploitation has proceeded with satisfying swiftness and will continue to do so for a while, although a slackening-off is apparent. For instance, new developments and new research angles are appearing at a noticeably slower rate, and there is an increasing tendency to sum up and define details rather than rough in the outlines of a new field. The slowing down seems to result from the exhaustion of basic data. Soon it will be necessary to give as much attention to basic biologic research as to

¹ This section was prepared by H. D. Bruner, M.D., Professor of Physiology, Emory University.

direct medical application. Learning to live without a comfortable stockpile will involve rearranging present research grant patterns as well as training increasing numbers of men in the basic sciences.

The emission of energy by a radioactive isotope is the particular property which makes it useful in medicine, in two ways. First, energy can be used to destroy unwanted tissue cells, as in a cancer. The rare statement about "stimulating doses of radiation" refers to the cellular repair phase which may follow limited tissue destruction. Particles or radiation originating in a reactor or accelerator have the same basic destructive effect on body tissues. In addition, neutrons are capable of inducing radioactivity in tissue components under special conditions. Second, the emitted energy provides a means of identifying the isotope as to location, quantity, and species with a sensitivity about one million times greater than that of the most sensitive chemical method. In some instances the radioactive atom can be substituted for a tedious chemical process, but more often radioisotopes have served to emphasize the absolute need for more and better analytical chemistry. Combining measurements on a radioactive isotope with an appropriate chemical analysis permits one to study dynamic body processes otherwise unobservable. In most studies the radioactive atom is employed as a label, usually by incorporating it into a stable complex molecule, but sometimes the elemental atom itself is used, as in trace element nutrition work with animals or plants.

The most active and rewarding field of all at present is the study of the complex synthesis and destruction of biochemical compounds which provide the energy of life; these compounds can be labeled in many different ways and then, by highly developed chemical techniques, traced in the life processes.² In Volume 213 (1955) of the *Journal of Biological Chemistry*, 53 per cent of the papers employed radioactive determinations as a central part of the technical procedures.

² "Research in Photosynthesis," and "Currents in Biochemical Research," Committee on Photobiology of the National Science Foundation, Papers and discussion presented at The Gatlinburg Conference, October 25-29, 1955; *Interscience Publication* (1956).

THERAPY

There are definite therapeutic uses of radioisotopes, but in most instances the radioactive isotope is but one of several agents available to the physician in treating a given disease. With the diminishing prospect of finding biological localizations anywhere near comparable to that of iodine-131 in the thyroid, greater attention is being given to mechanical emplacement and teletherapy machines. There are too many promising leads, however, even to suggest that new therapeutic uses will not develop.

The critical problem in radiation therapy has always been to confine the lethal energy to a rather sharply circumscribed mass of undesired or diseased tissue. Ideally, the surrounding normal tissue should be undamaged, or at least not damaged beyond recovery. In the case of the X-ray tube, the beam is aimed at a deep tumor from a succession of different angles so that any one area of skin receives only a fraction of the total dose which the tumor accumulates. Radium, as a mixture of naturally occurring radioactive isotopes, has been available for about forty years, so that its use is well docketed. It has been standardized in the form of sealed needles or encapsulated plaques which can be placed in prescribed patterns in contact with the tissue to be destroyed. The special rationale attending direct placement is the physical law which states that the radiation intensity varies inversely as the square of the distance from the source.

When reactor-produced radioactive isotopes became available, a new mode of localizing the radiation—biochemical emplacement—presented itself. Here one relies on the capacity of certain tissue cells to absorb a particular radioactive atom or labeled compound and then concentrate it in their protoplasm. There are two principal ways of accomplishing this: a) selective uptake, such as the specificity the thyroid has for iodine in manufacturing thyroxin; b) the differentially faster incorporation of a general cellular component, such as more rapid synthesis of phosphorus into the nuclear acid of wildly reproducing cancer cells.

The first of these has been put to valuable use in destroying thyroid tissue. The cells of the thyroid gland are the classic example of selective concentration of a substance. For example,

under special circumstances the iodine-131 concentration of the gland can be as much as 10,000 times greater than that in the blood. This factor, coupled with the favorable radiation emission of the abundant iodine-131, has made possible a highly effective method of treating hyperthyroidism. Many clinicians consider it the treatment of choice and prefer it to the surgery or anti-thyroid drugs such as propylthiourea. A recent review of ten years' experience with radio-iodine-therapy reported an effectiveness of 95 per cent with only 8 per cent of the patients showing evidence of overdosage.³

The results of iodine-131 treatment of thyroid cancers have been less brilliant because only about 15 to 25 per cent of neoplastic thyroid tissue will concentrate iodine-131.⁴ Also, a thyroid cancer which does concentrate iodine-131 will not do so evenly throughout its mass; radioautographs show areas of irregular high and low concentrations. Nevertheless, in those cases where iodine-131 has localized, the results have been brilliant, particularly when aberrant or metastatic thyroid tissue had to be dealt with. There is hope that research on normal thyroid function using iodine-131 will result in methods of inducing a larger percentage of thyroid cancers to concentrate iodine-131. Some types, however, are so anaplastic as to be quite hopeless for iodine-131 therapy. Astatine-211 may prove to be superior to iodine-131 for such uses, but there is still much work to be done from the biological and technical production side.

Controlled destruction of the thyroid by iodine-131 has recently become established for the treatment of congestive heart failure, intractable angina pectoris, and pulmonary emphysema.⁵ By reducing the amount of thyroid tissue, the metabolic rate of the body and hence the work load on the embarrassed organ is reduced. The patient simply obtains relief; he is not cured.

Other radioisotopes which might be suspected to localize in bone tumors, such as gallium-67 or gallium-72, have failed to

³ E. M. Chapman and Others, "Ten Years Experience with Radioactive Iodine," *Journal of Clinical Endocrinology*, XIV (1954), 45-55.

⁴ M. Sonenberg, "Physiologic Concepts in the Genesis and Management of Thyroid Tumors," *American Journal of Medicine*, XX (1956), 710-718.

⁵ H. L. Blumgart and Others, "Treatment of the Incapacitated Euthyroid Cardiac Patient with Radioactive Iodine," *Journal of the American Medical Association*, CLVII (1955), 1-4.

yield high enough concentration ratios under actual test in man.⁶ Nevertheless, there always remains the possibility that an isotope can be incorporated in a molecule which will be selectively retained. A few tentative studies along this line have been done. One of the most interesting is the incorporation of chromium-51 or phosphorus-32 into colloidal CrPO_4 [chromic phosphate] which, if the particles are of appropriate size, is scavenged by the reticulo-endothelial system [cells, scattered through various organs and tissues, which are thought to be concerned primarily with phagocytosis, or the ingestion and digestion of other cells]. Unfortunately, the R-E cells are too widely distributed to provide a really localized radiation dose. Specific tumors of the R-E cells are uncommon, but there is the possibility that neoplasms [tumors] related to these cells might phagocytize some form of radioactive material.

Because hyperplastic tissues [tissues, other than tumors, which proliferate] and tumor cells reproduce at supranormal rates, it is theoretically possible for such tissues to acquire more of a general tissue metabolite [product of metabolism or tissue-change] than the normal. On this basis polycythemia vera and chronic myeloid leukemia are treated by administering phosphorus-32 in small doses repeated as necessary. Many consider phosphorus-32 the treatment of choice in polycythemia, but in leukemia it is but one of the several treatments that are used in sequence to retard the progress of the disease. In both diseases, the phosphorus-32 is only palliative, not curative. In other forms of leukemia, treatment with phosphorus-32 seems to exaggerate the disease.

Other radioisotopes, such as sodium-24 and potassium-42, which also enter into the broad pattern of cellular metabolism, have proved less valuable for irradiating tumors differentially than for studying dynamic turnover rates in body fluids.

Concomitantly with biochemical localization, studies on physical placement have gone forward along lines suggested by the earlier uses of radium applicators. The use of cobalt-60, gold-198, and irridium-192 as colloids, wires, slugs, beads, or needles offers several distinct advantages over radium or radon, not the least of

⁶ M. Brucer and Others, "A Study of Gallium," *Radiology*, LXI (1953), 534-613.

which are cost, ease of manipulation, and better matching of the type of radiation to the condition being treated. A recent promising development is the implantation of a plastic bead containing strontium-90 in the sella [the "saddle" which divides the middle cranial fossa or hollows] to produce a discrete hypophysectomy [excision of the pituitary body] in patients with metastatic cancers affected by gonadotropins [substances which stimulate the gonads].⁷ In similar fashion such pellets might be able to destroy discretely localized tumors or metastases in liver, bone, lymph nodes, lung, central nervous system, and so on, where surgery is either impossible or undesirable. Strontium-90, made up in special applicators, is now the preferred agent for treating conditions of pterygium, vernal catarrh, vascularizations, tumors of the lid and conjunctiva, etc. Phosphorus-32 incorporated in a shaped Bakelite shell has been proposed as an alternate to strontium-90 because of the shorter range of the beta particles of phosphorus-32.

Infiltration of radioactive colloids into neoplastic tissues by syringe and needle has given partly acceptable results. Infiltration of tumors in well encapsulated organs, such as the prostate, seems to be a reasonably acceptable technique,⁸ but deposits in pliable or highly vascular organs disperse too easily into the normal tissues.

An accepted treatment of cancers which seed peritoneal or pleural surfaces is the intracavitary administration of large doses of colloidal gold-198. The desired effect is not suppression of tumor growth, although that was the theory on which colloidal Zn^{63}O_2 [radioactive zinc peroxide] was first tried in 1945, but rather a reduction in the rate of accumulation of fluid in these cavities. Such a reduction occurs in 50 to 70 per cent of cases, much to the comfort of the patient and relief of circulatory embarrassment. Although some cells floating free in the peritoneal

⁷ E. T. Rasmussen and Others, "The Destruction of the Pituitary Gland in Metastatic Cancer with Yttrium-90 Pellets," Argonne Cancer Research Hospital, Semi-annual Report to the AEC, March, 1955.

⁸ W. M. Rounds and T. C. Evans, "Recording of Radioactivity in the Blood, Liver and Prostate Following Interstitial Administration of Gold-198 in Carcinoma of the Prostate," *American Journal of Roentgenology*, LXXV (1956), 1132-1138.

fluid may be killed, the treatment is not curative; but the relief is definitely worthwhile.⁹

Other colloids such as $\text{CrP}^{32}\text{O}_4$ [radioactive chromic phosphate], $\text{Ti}_3(\text{P}^{32}\text{O}_4)_4$ [radioactive titanic phosphate] and the oxides of the rare earths are being investigated as substitutes for gold-198, because gold-198 has too short a half-life and its undesirable gamma rays needlessly irradiate distant normal tissues.¹⁰ A variant of the intracavitary gold-198 technique consists of the controlled introduction of gold-198, sodium-24, or bromine-82 into other cavities such as the urinary bladder.

Use of the gamma rays from a shielded radium aggregate as an alternate to high voltage directional X-ray tube therapy is a project dating back at least to 1918, but the capital cost of the radium and its relatively low dosage rate at usual working distances did not allow it to compete with the stable, controllable high voltage X-ray therapy tubes which came on the market. With the advent of reactor-produced gamma emitting radioisotopes, however, the prospect is reversed. Cobalt-60 and cesium-137 can be prepared in highly concentrated form: A one-half-cubic-inch piece of cobalt-60 can be activated to emit gamma radiation equivalent to that from thousands of grams of radium. The current problems in this field are production, handling, shielding, engineering the final working machine, and evaluating the clinical results. The special advantages are the low initial cost, the easily controlled small mass of the machine, the purity and hardness of the beam, and the negligible maintenance cost. A four-cubic-foot "cobalt bomb" provides a beam whose quality is equal or superior to that from a two-million-volt X-ray machine which would occupy two or three rooms; a similar cesium-137 teletherapy machine will be analogous to a one-million-volt X-ray machine. The cobalt-60 is produced by absorption of undefinably expensive neutrons, whereas the cesium-137 is a waste product of nuclear fission which

⁹ J. M. Dennis and Others, "Radioactive Colloidal Gold in the Control of Malignant Effusions," *American Journal of Roentgenology*, LXXV (1956), 1124-1128; H. B. Elkind and W. C. Keetel, "Radioactive Gold in the Treatment of Ovarian Carcinoma," *American Journal of Roentgenology*, LXXV (1956), 1117-1123.

¹⁰ H. C. Dudley and T. G. Mitchell, "A Study of Methods for Interstitial Implantation of Radioactive Materials," *American Journal of Roentgenology*, LXXV (1956), 1084-1092.

is readily extracted from spent uranium fuel rods. As of January 1, 1956, there were forty-four cobalt-60 units of more than 600 curies in use in this country, twenty-six of which were above the 1,000-curie level. The largest was a 1,900-curie source at the University of Michigan.¹¹ There is only one cesium-137 machine in use, but the automatic separator plant at Oak Ridge is now in operation and soon there will be more.

If there were adequate numbers of trained personnel, there is no reason why every Hill-Burton type of hospital or county clinic could not make high voltage radiation therapy available to its patients for an over-all cost equivalent to one or two hospital rooms.

Two related developments should be mentioned because they suggest such promising lines of research. With the evolution of particle accelerators, it has become possible to produce well-defined beams of different atomic particles having very high energies. Such particles appear not to conform to the usual rules of energy transfer. One of the most unusual differences is the very localized type of deep radiation damage, such as hypophysectomy, secured with minimal surface effects.¹²

The other variant involves an attempt to cause a tissue to localize or concentrate a substance which has a high capture cross-section for thermal neutrons. When capture occurs, the reaction releases an intense burst of radiant energy which is more concentrated than that from a disintegrating radioisotope due to the size of the particles.¹³ One such substance is bismuth-10 which gives rise to two intensely tissue-destructive particles when it captures a thermal neutron brought out of a reactor via a special port. The problem here, as with other biological localizations, is to find the time concentration conditions providing a workable differential. Work to the present suggests that certain types of brain tumors may show a practicable though transient differential,

¹¹ L. H. Hempelmann and S. Warren, "Atomic Energy in Medicine," in *Peaceful Uses of Atomic Energy*, II, 141-46.

¹² C. A. Tobias and Others, "Irradiation of the Pituitary of the Rat with High Energy Deuterons," *American Journal of Roentgenology*, LXXII (1954), 1-20.

¹³ L. E. Farr and Others, "Neutron Capture Therapy with Boron in the Treatment of Glioblastoma Multiforme," *American Journal of Roentgenology*, LXXI (1954), 279-93.

but it is not clear whether this is a property of the tumor or the blood-brain barrier or both.

To facilitate these and other studies on the biological properties of neutrons, a special reactor is being designed for medical use at Brookhaven National Laboratory. Also, at the M. D. Anderson Hospital and Tumor Institute of the University of Texas an extensive program is being developed around a versatile 500-kilowatt reactor. The program includes "experimental clinical work with external beams of neutrons and gamma rays for therapeutic purposes, and with isotopes, particularly short-lived isotopes, for investigational purposes and further to provide a neutron facility for fundamental studies in radiation biology, radiation chemistry and radiological physics."¹⁴

DIAGNOSIS

At present the diagnostic applications of radioactive isotopes are rather few and, with one or possibly two exceptions, not really impressive. The exception, the iodine-131 assay of thyroid function, is an excellent example of the refinement of a biochemical peculiarity into a reliable practical test. It has supplanted older, less critical tests of thyroid function. It seems likely, however, that increasing concern with unnecessary exposure to radiation will demand that proposed tests be of demonstrated superiority. In so far as biochemical changes precede structural defects, turnover rate studies with radioisotopes may provide a means of anticipating and modifying such deterioration.

The reliable diagnostic test represents the essence of a careful, broad study of an established phenomenon. The reliability of the test, however, must be proved by many independent workers. Because this calls for an appreciable lapse of time and reasonable standardization of instruments and procedure, the general status of diagnostic tests employing radioactive isotopes is not yet of a high order. Not one of the diagnostic tests discussed here is fool-

¹⁴ W. K. Sinclair, "Nuclear Reactor Project, University of Texas M. D. Anderson Hospital and Tumor Institute, October 1955," in *Peaceful Uses of Atomic Energy*, II, 139.

proof, completely standardized, or unique in the sense that no other test might give comparable information.

The same restrictions apply to nearly all other diagnostic tests, but because their basic techniques are more familiar, their limitations are apt to be better recognized. The radioactive diagnostic test should be regarded simply as another in the battery of tests bearing on the diagnosis under consideration. Tests using isotopes should never be ordered without recognizing that the radiation from the isotope will add to the patient's cumulative radiation dose.

Many diagnostic procedures using radioactive substances have been proposed, but only a few are in use; probably such survival is the only criterion of fitness. They may be classified under the headings of physiologic localizations, dilution techniques, flow or diffusion measurements, and fate of metabolites.

The most widely used diagnostic test is based on the affinity of the thyroid for iodine-131, leading to the formation of tetra-iodothyronine or thyroxin. Briefly, it has been found that the hyperactive thyroid accumulates iodine-131 at a faster rate and ultimately to a greater extent than the normal. Concomitantly, it converts iodine-131 into thyroxin more quickly and discharges the labeled thyroxin into the blood stream more rapidly, resulting in a higher than normal level of plasma "protein-bound iodine." In hypothyroidism the reverse occurs, but the difference from the normal is much less, so that frequently a problem arises in trying to decide whether a given value is a low normal or a moderate hypothyroid. At least ten distinct diagnostic procedures have been proposed, with variations relating to timing, dose of iodine-131, and detecting equipment. All claim excellent reliability in discriminating between hyperthyroidism and the normal, and quasi-reliability between hypothyroidism and normal.¹⁵ Only recently have data begun to appear which will permit elimination of the less worthy procedures. This will not be simple because the accuracy of a procedure depends in part on the skill of the operator relative to his confidence in it. In that connection, a recent survey of the accuracy of thyroid retention data by external "scanning"

¹⁵ W. M. McConahey and Others, "Clinical Appraisal of Radioiodine Tests for Thyroid Function," *Journal of Clinical Endocrinology*, CLX (1956), 724-34.

methods gave values ranging from 20 per cent to 120 per cent uptake when the known standard mock-up was set to 70 per cent uptake.¹⁶ The need for standardization and internal checks is obvious.

External scanning of the thyroid is quite useful, however, in searching out aberrant tissue, metastases, and nodules, provided the tissue is an iodine segregator. The absence of a hotspot [a place which reveals radioactivity], therefore, is not evidence of freedom from metastases. A highly engineered development is the "scintiscanner" which electronically moves a detector in a pre-determined coordinate pattern over an area and prints the intensity of radiation in terms of the width of a line of a fixed height. The resulting pattern shows an outline of the gland relative to the intensity of iodine-131 radiation. Some workers claim that it permits a fairly accurate estimate of the weight of the gland.¹⁷ All these tests are completely worthless if the patient has been taking iodine in any form, including most of the proprietary cough medicines. The iodine of iodinated oils for bronchography will nullify all these radioiodine tests up to a year later, and anti-thyroid drugs will cause a hypothyroidism to be reported. Despite all drawbacks, however, most workers consider these tests superior to the basal metabolism test, the blood cholesterol, and non-radioactive protein-bound iodine determinations.

For the same reasons that phosphorus-32 might concentrate in cancerous tissue, it has been employed in attempting to identify neoplastic areas. The five-millimeter range of its beta particle, however, has limited such studies to lesions contiguous to a surface or to tissues into which a needle-type counter could be inserted. Thus, there are reports dealing with differentiation between malignant and benign breast cancer, identification of tumors of the eye, gastrointestinal tract, uterus, vagina, and brain, and estimation of the integrity of the blood supply to the head of the femur following fracture of its neck. Both reliable and

¹⁶ M. Brucer, "Thyroid Uptake Calibration Program," Midyear Report, Medical Division, Oak Ridge Institute of Nuclear Studies, December 30, 1955, 40-43.

¹⁷ W. E. Goodwin and Others, "A Method Using Iodine-131 for the Determination of Abnormal Thyroid Morphology," *American Journal of Roentgenology*, LXI (1953), 88-92.

equivocal results have been obtained,¹⁸ the most disheartening being that the avascular [without blood vessels or lymphatics] tumors failed to show a differential, while inflammatory lesions sometimes did. This line of study seems to have been discontinued except for efforts to distinguish between malignant tumors and other lesions of the anterior segment of the eye. Thus far, no one has devised a counter which could be applied to tumors of the posterior segment of the eye.

Part of the difficulty inherent in the use of phosphorus-32 is overcome by use of potassium-42, an element which all cells, but especially skeletal muscle, concentrate approximately twenty-five times relative to serum. The short half-life and the energetic beta and gamma radiation simplify detection but decrease the exactness of location. This isotope has been tested on tumors of the breast and brain with moderate success, but as with phosphorus-32, the absence of corroborating papers may be significant.

Certain radioisotopes such as copper-64 and arsenic-74 decay by emitting a positron which, on coming to rest after traveling a few millimeters, captures a free electron and changes into two annihilation photons oriented at 180°, with the source between. A coincidence circuit is added to reject all impulses except those which activate the counters simultaneously. To pinpoint a brain tumor, the paired counters would be moved through a fixed pattern around the head to obtain several positions of maximal counting rate. The tumor should lie at the intersection of the lines connecting the paired counters at these positions. In theory and in mock-up the procedure works beautifully but in man less well, because tissues other than the tumor also pick up the positron emitter or the molecule in which it has been incorporated.¹⁹ The problem to be solved is not so much concerned with the electronics and geometry as it is in finding a substance in which tumors will concentrate by a factor of at least fifty. This

¹⁸ B. Roswit, J. Sorrentino and R. Yalow, "The Use of Radioactive Phosphorus (P^{32}) in the Diagnosis of Testicular Tumors," *Journal of Urology*, LXIII (1950), 724-28; J. W. Bettman and V. Fellows, "Radioactive Phosphorus as a Diagnostic Aid in Ophthalmology," *Archives of Ophthalmology*, LI (1954), 171-79.

¹⁹ G. L. Brownell and W. H. Sweet, "Localization of Brain Tumors with Positron Emitters," *Nucleonics*, XI (1953), No. 11, pp. 40-45.

procedure has definite theoretical advantages over the single-counter technique below.

The possible diagnosis of bone tumors by use of gallium-67 and gallium-72 has been thoroughly investigated, with discouraging results. The uptake of this metal by bone tumors was unpredictable, although spottiness without reference to histologic characteristics of the tumor or any other recognizable physiologic feature occurred. These isotopes also failed to modify the clinical course of several types of bone tumors.

The diagnostic procedure given the most thorough examination is the localization of iodinated human serum albumin (IHSA) in or around a brain tumor. Iodine labeled diiodofluorescein (DIF) has also been used interchangeably with IHSA. DIF differs from IHSA in its more rapid rate of transport, turnover, and excretion.

The capillary exchange in the central nervous system appears to be more restricted than elsewhere in the body because of the poorly understood "blood-brain barrier," but in the presence of certain types of tumors, especially metastatic cancers, the barrier breaks down. Large molecules that formerly remained in the blood stream now leak out into the neoplastic area and produce a differential concentration of material labeled with iodine-131. Systems of external counting have been proposed which vary from counts over 36 symmetrical predetermined spots to complete polar coordinate scanning systems. The accuracy of localization has varied from 5 per cent to 90 per cent in the hands of different workers. This divergence is due only in part to the fact that certain tumors such as astrocytomas, angiomas, or oligodendrogliomas are missed more often than others. Conclusions as to the value of this test range from "hardly reliable" and "unproved"²⁰ to "worthwhile" and "enthusiastic indorsement."²¹ However, not much has been published recently about this work.

IHSA and DIF have also been used to delineate space-occupying lesions of the spinal canal. The labeled compound was introduced

²⁰ H. J. Svien, J. G. Rushton and E. J. Baldes, "Localization of Brain Lesions by Means of RISA," *Proceedings of Staff Meetings, Mayo Clinic*, XXIX (1954), 478-85.

²¹ M. Ashkenazy and J. W. Crawley, "The Value of Serial Studies of Cerebro-Vascular Permeability with Radioactive Iodinated Serum Albumin and the Scintillation Counter, Particularly in the Detection of Neurosurgical Lesions," *American Surgeon*, XIX (1953), 155-64.

into the subarachnoid space, and its spread followed by an external collimated counter over the spine. Points of low counting corresponded to the lesion. It is not clear whether this procedure was deemed superior to ordinary myelography [visualization of the spinal cord].

Since DIF is excreted via the liver and gall bladder, the emptying of the latter organ can be detected from surface counting following an intravenous injection of the agent. However, this proved inferior to ordinary cholecystography [visualization of the gall bladder] in that it did not provide information on the presence of stones.

Lesions in the liver have been outlined by surface-scanning over the organ following an intravenous injection of colloidal gold-198 or IHSA. Metastases, abscesses, and hepatomas replace the normal reticulo-endothelial cells and/or the vascular bed with the result that low counting areas can be defined. Poor results were obtained if the lesions were too deep or if ascites [abdominal dropsy] or acute hepatitis were also present. A liver function test is performed with iodine-131 labeled Rose Bengal, a dye taken up by the polygonal cells of the liver preparatory to its excretion via the gall bladder. Its clearance from the blood stream has been tried and discarded in the past because it was not sensitive enough, but the rates of build-up and decline of activity as measured by an external counter located over the liver may give a useful test.²²

The basic principle has been used for many years to measure plasma volume by Evans' Blue dye or T-1824 and to estimate the volume of certain fluid compartments of the body. In addition to improving and facilitating the analytical procedures, substituting a radioisotope or labeled substance has extended the principle into a new area, the dynamics of metabolic turnover. Work of this type has given rise to the concept of the "dynamic state of the body constituents," a description of the fact that the components of a body "pool" change with time, although the pool itself remains essentially constant.²³

²² G. V. Taplin, O. M. Meredith, Jr., and H. Kade, "Radioactive Iodine-131-tagged Rose Bengal Uptake-Excretion Test for Liver Function Using External Gamma-ray Scintillation Counter Techniques," *Journal of Laboratory and Clinical Medicine*, XLV (1955), 665-78.

²³ R. Schoenheimer, *The Dynamic State of Body Constituents* (Cambridge: Harvard University Press, 1942).

Some of the labels and physiologic processes measured are: (1) deuterium or tritium to measure total body water; (2) autogenous red cells labeled by contact *in vitro* with phosphorus-32, potassium-42, or chromium-51 for total circulating red cell volume; (3) compatible transfusion of red cells labeled *in vivo* by hemoglobin containing iron-55 or iron-59 for measurement of red cell volume. The iron must be injected into the animal or man who is to donate the cells, the radioactive iron being used by the donor's bone marrow to label the hemoglobin;²⁴ by first using cells labeled with iron-55 and then cells labeled with iron-59, a double tracer experiment is possible; (4) iodinated human serum albumin to measure total plasma volume; (5) sodium-24 to measure the sodium space; (6) potassium-52 to measure potassium space; (7) 4-iodoantipyrine to measure a body water compartment; (8) chlorine-36 to estimate the chloride space; (9) bromine-82 to measure a fluid compartment; (10) $\text{Na}_2\text{S}^{34}\text{O}_4$ [radioactive sodium sulphate] or radio-thiosulfate to measure a poorly defined "space," and (11) KS^{35}CN [radioactive potassium thiocyanate] to measure the thiocyanate space.

Accurate measurements of the size of the red cell and plasma volume are not especially helpful in establishing a diagnosis, since significant changes in either or both usually develop only after the condition is so far advanced that diagnosis is not the problem. Consequently, these and the body water compartment measurements are carried out largely in clinical research laboratories for research purposes. Perhaps the greatest importance of these measurements lies in their use as indices of the extent and severity of a disease process in order to achieve a more precise prognosis and treatment. Nevertheless, it must be granted that the experienced clinician rarely fails to prescribe the needed amounts of the proper replacements. The fact that the body water and its composition are strongly supported by several homeostatic mechanisms permits considerable latitude. On the other hand, if such tests were better developed and in wider use, it is probable that the treatment of cardiovascular-renal and certain endocrinological diseases would be improved.

²⁴ J. G. Gibson, II, and Others, "Measurement of Circulating Red Cell Volume by Means of Two Radioactive Isotopes of Iron," *Journal of Clinical Investigation*, XXV (1946), 616-26.

In computing the volume of the body compartments, the radioisotope was considered to have been diluted in water, but it is also diluted in the stable isotope normally present in the body. For example, following injection of a known amount of radioactive sodium-24, the activity of sodium-24 per milliliter of plasma relative to the concentration of stable sodium-23 would then provide a measure of the total exchangeable sodium in the body. The degree of dilution of the sodium-24 in the sodium-23 per ml would be determined at intervals until the ratio became essentially constant. Probably of equal importance is the time required for equilibrium, since it is a measure of the time required for attaining a dynamic physiologic balance.

At present, data are beginning to appear in the literature on the total exchangeable sodium, phosphorus, serum albumin, and by a somewhat more sophisticated procedure the exchangeable thyroid hormone pool.²⁵ Adding data on total exchangeable ions to the "Gamblegram" is of obvious importance in studying many diseases, and in time practical diagnostic procedures ought to evolve from these purely research techniques. From the rate data which describe dynamic processes, it is conceivable that a measure of one aspect of physiologic age might be developed. In brief, the dilution technique can be exploited in many ways for diagnostic purposes, but such work is just getting under way.

A circulation time test proposed in 1924 was the first diagnostic procedure to use radioactive isotopes.²⁶ Subsequently, sodium-24 and other radioisotopes have been proposed for various circulation times chiefly because the isotope provides a convenient objec-

²⁵ R. S. Yalow and S. A. Berson, "Some Applications of Isotope Dilution Studies," *American Journal of Roentgenology*, LXXV (1956), 1059-1067; C. V. Robinson, C. V. Arons, and A. K. Solomon, "An Improved Method for Simultaneous Determination of Exchangeable Body Sodium and Potassium," *Journal of Clinical Investigation*, XXXIV (1955), 134-40; S. A. Berson and R. S. Yalow, "Distribution of Iodine-131 Labeled Human Serum Albumin Introduced into Ascitic Fluid: Analysis of Kinetics of Three Component Catenary Transfer Systems in Man and Speculations on Possible Sites of Degradation," *Journal of Clinical Investigation*, XXXIII (1954), 377-87; and S. A. Berson and R. S. Yalow, "Quantitative Aspects of Iodine Metabolism: Exchangeable Organic Iodine Pool and Rates of Thyroidal Secretion, Peripheral Degradation and Fecal Excretion of Endogenously Synthesized Organically Bound Iodine," *Journal of Clinical Investigation*, XXXIII (1954), 1533-1552.

²⁶ H. L. Blumgart and O. C. Yens, "Studies on the Velocity of Blood Flow. I. Methods," *Journal of Clinical Investigation*, IV (1927), 1-15.

tive endpoint. The recent concern for the total cumulative radiation dose may cause a shift to one of several nonradioactive substitutes.

A technique for evaluating the circulation to a local area, such as the foot or a skin flap, has been based on the rate of build-up of a gamma ray emitter in the area. In general, the more active is the circulation, the faster is the rate of accumulation of sodium-24. For example, a roughly quantitative comparison of the rate of build-up and the final concentration of sodium-24 in a suspected gangrenous limb with that in the normal limb would give a means of evaluating the blood supply or of choosing a level for amputation. One of the originators of this test, however, has recently pointed out that "before any one of these circulation tests becomes a useful diagnostic aid, much will have to be done toward standardizing conditions."²⁷ The biologic and environmental conditions which need to be standardized are also unsolved problems in other types of current physiologic research and not peculiar to the demands of the radioactive isotope.

Dissipation of a tiny intramuscular deposit of sodium-24, detected by an external counter, has been proposed as a method for estimating blood flow through muscle, on the assumption that the factor limiting dissipation is clearance of the capillaries by blood flow rather than diffusion from the tissue spaces into the capillaries.²⁸ Changes in shape of the disappearance curves have been shown to match the expected physiological changes in blood flow, but the timing has not always agreed, due in part at least to seepage of some of the sodium-24 along the track of the needle back into the subcutaneous tissue. The procedure has not been accepted for diagnostic purposes, although the basic concept is sound. It is possible that use of modern reliable scintillation counters will eliminate some of the major objections which have been recorded.

Radiocardiography is the name given to a procedure which records the gamma radiation pattern detected as a slug of sodium-24 progresses through the right heart, lesser circulation,

²⁷ E. H. Quimby, "Isotope Studies on Blood Flow and Blood Cells," *American Journal of Roentgenology*, LXXV (1956), 1068-1081.

²⁸ S. S. Kety, "Measurement of Regional Circulation by Local Clearance of Radioactive Sodium," *American Heart Journal*, XXXVIII (1949), 321-28.

and left heart.²⁹ A heavily shielded fast counter, collimated on the heart, records a peak as the sodium-24 reaches the right side of the heart, then a dip as it passes to the lungs, and finally a second peak as the sodium-24 returns to the left heart and passes into the aorta. Cardiac defects which modify this sequence produce corresponding changes in the pattern and contours. This technique, however, has not been exploited, partly because of the difficulty of maintaining a supply of the short-lived (14.8-hour half-life) sodium-24. In that connection the location of experimental or therapeutic reactors near medical research centers would provide a continuous supply of sodium-24 and other short-lived isotopes for developmental studies.

The Hamilton method for measuring cardiac output has been adapted for radioactive isotopes by substituting a small slug of iodinated serum albumin for the dye and by leading the blood from the artery into a special Geiger counter instead of the rotating collecting tubes.³⁰ The curve of concentration with time is similar to that obtained with dye and is analyzed in the usual way. Although the method is reliable, most investigators seem to prefer the catheterization (Fick) procedure for cardiac output.

Currently under development and testing is a method using krypton-79 in place of N_2O for measurement of cerebral blood flow. Substituting external counting for the time-consuming blood gas analyses would be an important step in making cerebral blood flow measurements a practical diagnostic test.

The fate of metabolites has been relatively neglected, but this category of diagnostic procedure may prove to be the most productive. Undoubtedly, some of the biochemical studies currently in progress will provide the basic data from which future diagnostic tests will be devised. Three such developments can be cited.

Vitamin B_{12} contains cobalt as the essential metal of its complex structure, and so the vitamin can be easily tagged for biochemical and tracer studies. Absorption of B_{12} from the intestine has been found to depend on the presence of the "intrinsic factor"

²⁹ M. Prinzmetal and Others, "Radiocardiography and its Clinical Applications," *Journal of the American Medical Association*, CXXXIX (1949), 617-22.

³⁰ W. J. MacIntyre and Others, "Iodine-131 Labeled Serum Albumin: Its Use in the Study of Cardiac Output and Peripheral Vascular Flow," *Radiology*, LIX (1952), 849-57.

which is secreted by the normal mucosa of the stomach.³¹ In pernicious anemia there is failure of secretion of this intrinsic factor; consequently, there is an inadequate absorption which leads to a clinical deficiency state. Other conditions may simulate the deficiency state, so that a differential diagnosis eventually narrows down to whether the stomach is secreting the intrinsic factor. This can now be very simply tested by administering orally a few micrograms of cobalt-60 labeled B_{12} , plus stable B_{12} carrier, and collecting the urine. The patient with pernicious anemia absorbs from the gut and then excretes in the urine a definitely smaller percentage of the oral dose than does the normal. The deficient absorption can be pinpointed by administering a dried defatted stomach preparation containing the intrinsic factor with the labeled B_{12} . After such administration the urinary cobalt-60 excretion increases into the normal range.

Radioactive iron as an essential component of hemoglobin is incorporated into the developing red cell following an intravenous tracer dose of iron-55 or iron-59 attached to fresh plasma protein or to fraction IV-7 globulin. The latter form is preferred because it is identical with that of circulating plasma and hence deranges the plasma least.³² Studies on patients show that the most rapid rates of clearance of radioactive iron from the plasma and incorporation into the red cell are found in conditions where the rate of red cell formation is highest and/or the iron supply is most deficient. In general, the reverse is also true. In an iron deficiency anemia as much as 95 per cent of an injected tracer dose will become iron-55, iron-59 hemoglobin within seven to eight days, compared to about 75 per cent incorporated in about fifteen days in the normal. The rate of utilization of a tracer dose of iron can, therefore, be used as an index of erythropoiesis [process of forming red blood cells] provided that the status of the available and fixed iron stores and the plasma iron pool is controlled or has

³¹ R. F. Schilling, "Recent Studies of Intrinsic Factor and the Utilization of Radioactive Vitamin B_{12} ," *Federation Proceedings*, XIII (1954), 769-75; W. R. Best, W. F. White and J. Louis, "Use of the Schilling Test in Pernicious Anemia," *Journal of Laboratory and Clinical Medicine*, XLIV (1954), 767-68.

³² P. J. Emlinger, R. L. Huff, C. A. Tobias, and J. H. Lawrence, "Iron Turn-over Abnormalities in Patients Having Anemia: Serial Blood and *in vivo* Tissue Studies with Fe^{59} ," *Acta Haematologica* (1953), No. 9, p. 73.

been standardized. The diagnostic possibilities in such studies are still to be explored.

Such labeled red cells made possible the studies which selected the best ACD blood preservative media during the war. Deterioration and/or death of the cell was readily detected by the appearance of radio iron outside the red cell mass.

Cholesterol labeled with hydrogen-3 is distributed between the plasma and cells and metabolized in a characteristic fashion by the normal, but in the arteriosclerotic patient the pattern is different. The concentration of hydrogen-3 was highest in the free cholesterol fraction of normal plasma, whereas it was lowest in the arteriosclerotic. To be of diagnostic value this observation will require many additional studies, but it has been noted because it is of the type which conceivably might provide a means of early diagnosis.

RESEARCH

It is impossible not to be completely optimistic about the future of the radioisotope in research. The limitations of the methods have been rather clearly marked out so that even the beginner can employ isotopes with confidence in his ability to use them properly.

How fast and how far research with radioactive isotopes advances would seem to depend simply on the number of investigators, their energy, and their imagination. Or again, "The result has been a great reawakening in some areas of understanding of disease processes and diagnostic problems that have probably advanced us by a quarter of a century at the present time over where we would have been had these tools not been available."³³ It is true that the radioactive isotope is a tool, but this tool seems to have the Midas touch.

Many investigators are beginning to feel that more emphasis

³³ J. C. Bugher, "Introductory Address," Section on Use of Radioisotopes in Medicine and Agriculture, *Atomic Energy in Industry*, 3rd Annual Conference, October 13-15, 1954 (New York: National Industrial Conference Board, 1955).

must be directed toward cultivating and sponsoring basic research in medicine and its allied sciences. Their concern is to make sure of a continuously increasing supply of basic biomedical data containing the elements from which can be crystallized the practical applications.

It should not be inferred, however, that basic medical research using isotopes has been inconsiderable. There have, in fact, been so many reports that a sizeable library staff would be needed to classify and annotate them. It has been noted that within the last five years "significant advances and changes in ideas have taken place. The descriptive phase of radiobiology has passed and investigations are more concerned with the mechanisms of the phenomena. The number of scientists engaged in research in this field has increased and concomitantly the number of publications has grown."³⁴ Under these circumstances possibly the most effective way of documenting how the radioactive isotope has enlarged medical horizons is to quote a few examples in various fields of medicine.

It had been known since the 1920's that certain compounds and foods were goiterogenic, that is, they interfered with the function of the thyroid gland in such a way that it enlarged. Following the demonstration that thiocarbamide compounds inhibited or blocked thyroxin synthesis in the gland, many groups undertook to find the compound which exhibited the greatest antithyroid activity for the least toxicity and had the required pharmaceutical properties. To accomplish this meant setting up a large screening program on animals. The occasional suitable clinical case of hyperthyroidism was reserved for a check on the compounds which passed the animal screening.

The screening method first used depended on a chemical analysis of the iodine content of the thyroid glands of the rat; this was slow and expensive, since groups of rats were required to establish each dose-response point on the curve for each of the three hundred or so compounds tested by one drug company. When it became known with the aid of iodine-131 that these compounds blocked the formation of thyroxin, it was possible to devise new screening methods which depended on the uptake of

³⁴ A. Edelmann, "Vertebrate Radiobiology," *Annual Review of Nuclear Science* (Stanford: Annual Reviews, Inc., 1955), V.

iodine-131 and so reduce the time for a complete assay from weeks to days. The iodine-131 uptake technique was modified still further into the prototype of the sixty-minute iodine-131 clearance technique and adapted for both man and monkey so that relative potencies could be defined quickly.

There can be no question but that the impetus behind this pharmaceutical development helped establish iodine-131 in studies of thyroid physiology. At present no one would dream of beginning any sort of research program on iodine metabolism or the thyroid without being equipped to use iodine-131.

In most instances the radioactive atom is simply mixed with the stable isotope carrier and the synthesis carried out as usual with only the standard health physics precautions against contamination and radiation dosage. Not infrequently new methods of synthesis have been devised in order to secure the highest possible yield in the step where the radioactive label [tracer] is attached. Many experiments have been unsatisfactory because the label was too diluted in the final samples to give reliable counting rates.

Some of the experiments dealing with the incorporation of cobalt-56, -57, and later cobalt-60, in vitamin B₁₂, may be cited as examples of how labeling compounds expands research frontiers.³⁵ Because ordinary chemical methods had not been sensitive enough to detect the microgram amounts of B₁₂ used for physiological and pharmacological purposes, a tedious microbiological assay had been developed. Later when the structure of B₁₂ was determined and a synthesis worked out, cobalt-56, -57 immediately was incorporated for tracer purposes.

Solely because of the radiocobalt label, complete absorption-distribution-excretion studies in rats and man demonstrated the need for a continuous daily supply of the vitamin. For one thing, it was poorly absorbed from the gut and rapidly excreted in the urine. All tissues were found to retain B₁₂, especially the liver and kidney, but the bone marrow and nervous system, which are markedly damaged by its deficiency, showed only average concentrations.

³⁵ C. Rosenblum, "The Use of Radioisotopes in the Fields of Medicinal Chemicals Manufactured," *Atomic Energy in Industry*, Special Conference, October 16-17, 1952 (New York: National Industrial Conference Board, 1952).

The stability of ten micrograms of B_{12} in multivitamin capsules was determined by means of the cobalt-60 label to be at least 80 per cent after thirteen months on the shelf.

Combining the isotope dilution procedure with appropriate solvent extraction techniques offered a means of quickly and positively measuring the B_{12} content of animal feed supplements, something for which the microbiological assay was ill-fitted. This procedure is now a routine examination for the product control division.

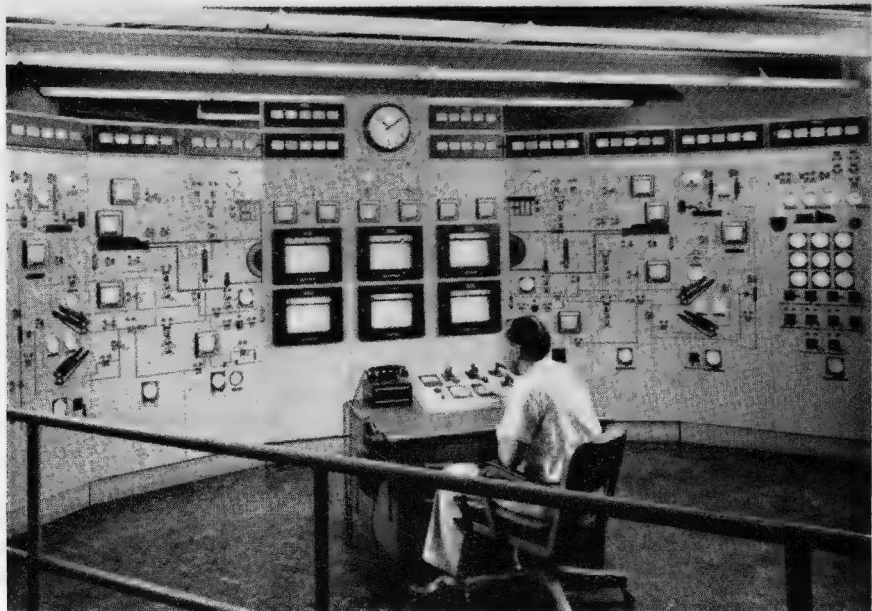
In all instances it was necessary to demonstrate that the detected radioactivity was still attached to the B_{12} , but this could be done by checking the radioactivity against the bio-assay activity in selected fractions obtained by water-benzyl alcohol partition. Subsequently, paper chromatography [analysis of pigments and other colored compounds] plus autoradiography simplified identification of the chemical forms.

In instances where the structure or synthesis of the compound is not known, raw materials such as $C^{14}O_2$ [radioactive carbon dioxide] and HTO are presented to the plant, bacterium, or animal which synthesizes the compound in the course of its normal metabolism. The harvested material then is processed by standard methods for radioactive components. In this way it has been possible to obtain labeled drugs such as digitalis, morphine, dextran, unusual sugars, and so forth. Such biosynthetic compounds are randomly labeled. The carbon-14 or hydrogen-3 is not found on any preferred location of the molecule. Such biosynthetics are suitable for all but a few special experiments where it is essential to learn at what points on a carbon-chain fragmentation occurred. For the latter purpose, special reactions have been developed to substitute a carbon-14 for a carbon-12 atom at a known point or to add a radical containing carbon-14 at a noncritical position.

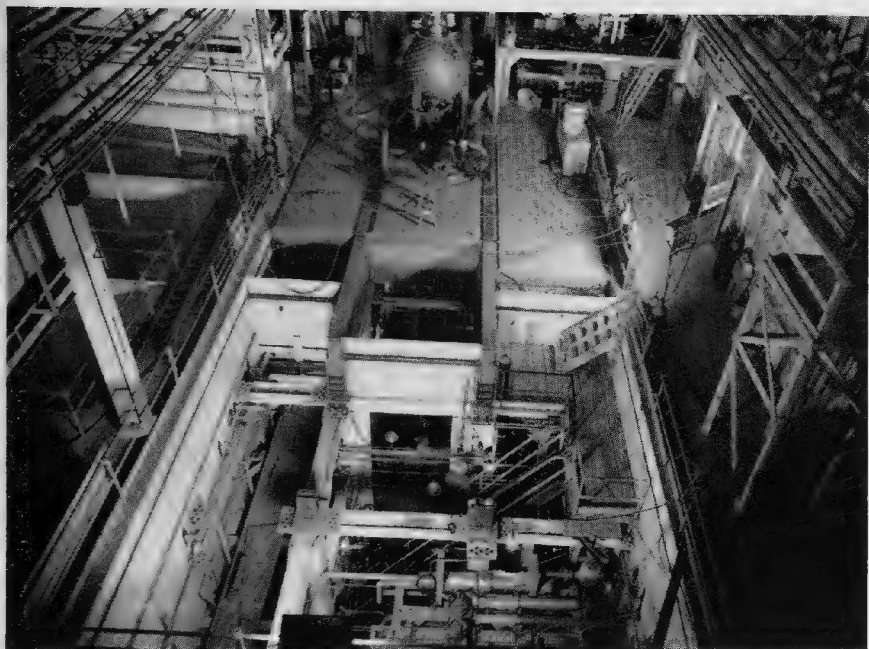
The present knowledge of photosynthesis in plants and intermediary metabolism in microorganisms and animals is to the credit of these synthetic and biosynthetic compounds. If for no other reason than the advances in these two fields, the flourishing "isotope farm" which has been in operation at the Argonne National Laboratory would be justified. Eventually the farm is expected to grow to the point of being able to feed labeled fodder



The Power Reactor Development Company, a nonprofit group of which The Southern Company (including the Alabama, Georgia, Gulf, and Mississippi Power Companies) is a member, is building this nuclear power plant in Michigan. Members of the Power Reactor Development Company will use knowledge gained from this project in designing their own nuclear power plants in the future.



The operator of the Homogeneous Reactor Test (HRT) facility at Oak Ridge National Laboratory sits at the control panels watching a maze-like group of instruments and diagrams. The fuel, "blanket," and low-pressure systems of the HRT are drawn on the control room board to simplify operation. The concept of reactors represented by the HRT involves a built-in fuel reprocessing system and has been vigorously championed by its developers at the Oak Ridge National Laboratory.



Workmen begin installing the core vessel (the ball-like object at top center) inside the "blast and shield" in the cell of the Homogeneous Reactor Test facility at the Oak Ridge National Laboratory. Concrete blocks like those in center background will cover the entire assembly when the HRT goes into operation.



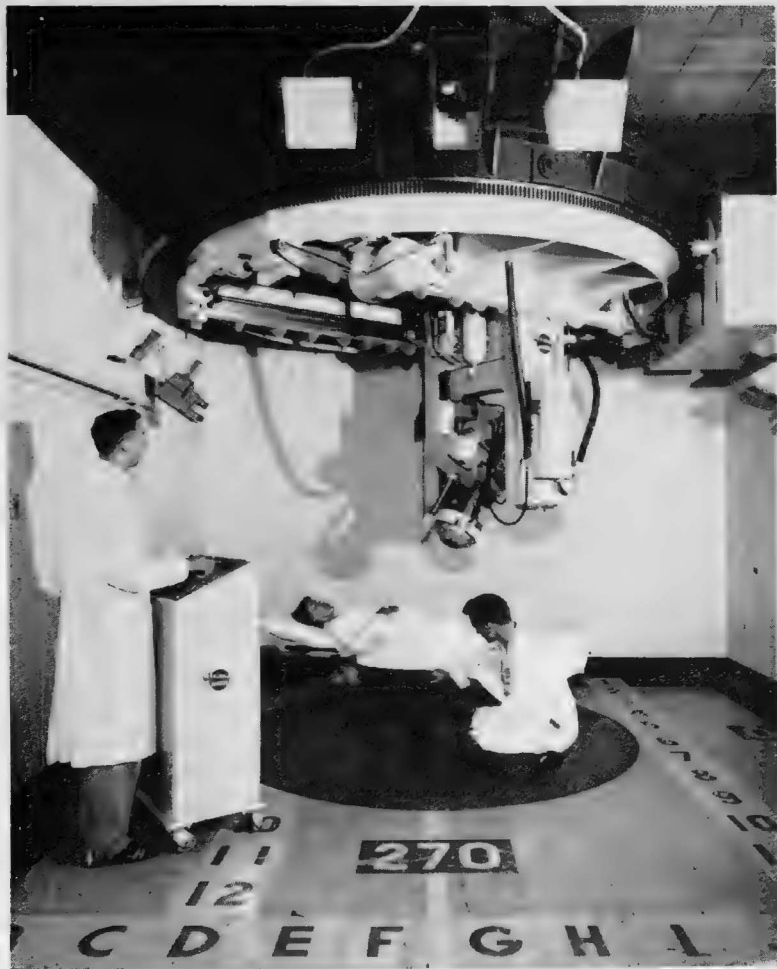
The device in the center, which contains radioactive irridium-192, makes radiographs (X-ray-like pictures) of the metal castings surrounding it. By using a string-and-pulley, the operator of this radiography unit, which is owned by Law-Barrow-Agee Laboratories, Inc., of Atlanta, raises a pellet of irridium-192 from the hole in the floor into the vertical tube. Rays from the pellet then penetrate the nine steel boiler return bends, each of which has sections of photographic film taped on the inside. The radiation penetrates the castings and marks the films, showing up flaws in the castings as a dentist's X-ray discloses flaws in teeth.—*Courtesy Law-Barrow-Agee Laboratories, Inc.*



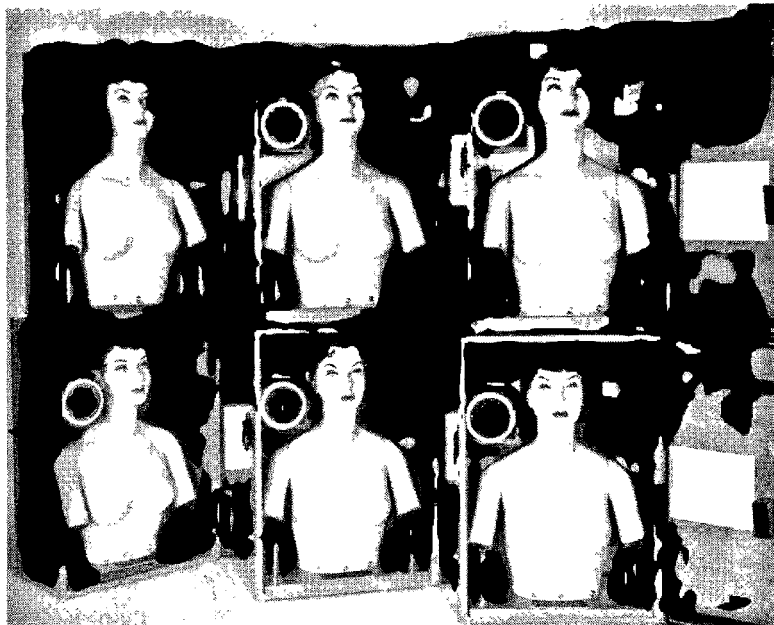
This photograph records the first operation of a plant irradiation facility at the Blandy Experimental Farm in Virginia on July 19, 1957. The table-like arrangement of slabs prevents gamma rays from leaving the pit, which contains radioactive material. The plants are ready for brief exposure of extremely great intensity.



The red flower in the center appeared on this white carnation plant following exposure of the young plant in a radiation field at the Brookhaven National Laboratory in 1954.—*Courtesy Brookhaven National Laboratory*



Staff members of the Medical Division of the Oak Ridge Institute of Nuclear Studies operate a 1,540-curie radiation source of the radioisotope cesium-137 as part of the teletherapy program. This device permits a moving beam of radiation to be focussed on diseased tissue in any conceivable spherical pattern. The patient's pallet and the irradiation unit revolve so that a long, strong dose of radiation may be administered to the desired tissue with minimum damage to surrounding healthy tissue; the ray is continuously focussed only on the spot the physician desires to reach.



The mannequins are used in a study conducted by the Medical Division of the Oak Ridge Institute of Nuclear Studies in which physicians at a number of Southern medical schools and hospitals have participated. The mannequins have simulated thyroid glands containing "mock iodine," which is a mixture of radioactive barium and cesium and which has characteristics similar to those of the radioisotope iodine-131 but a longer and therefore more useful radioactive life. The study is designed to achieve standard methods of measuring the absorption of radioactive iodine by the thyroid gland.

to animals which will return the label to the plants in a balanced economy. At the Medical College of Virginia a farm for growing carbon-14-labeled tobacco and nicotine has recently been established.

In another experiment the fate of reserpine, the tranquilizing alkaloid extracted from *Rauwolfia serpentina*, was studied by labeling the carboxyl group in the trimethylgalloyl portion of the molecule with carbon-14.³⁶ By use of counting techniques together with paper chromatography and carrier isolation methods, it was demonstrated that the nervous system, like the other body tissues, had no predilection for the drug even though its outstanding action is on the nervous system at doses of five to ten micrograms per kilogram body weight. These experiments also proved that reserpine is gradually hydrolyzed to trimethylgallic acid which is excreted by the kidneys into the urine.

The problem of selecting the conditions for the most complete crystallization of penicillin was easily solved by using penicillin labeled with sulphur-35. This was added to the freshly harvested liquor, and the conditions of crystallization varied.³⁷ All that was needed was to compare the activity in the supernatants with that in the mother liquors. If it had been necessary to rely on chemical or microbiological assay the true value would not have been obtained for these assays measure both penicillin and penicilloic acid, the degradation product of penicillin.

Possibly the most impressive evidence of the significance of labeled compounds is the sales literature from nearly every major radiation instrument sales organization. The national laboratories, university departments, and the research groups of commercial companies also stock certain items which they are now able to disburse on an informal basis.³⁸

A word of caution concerning labeled products should be added. Although the labeled compound may be known to be pure at the end of preparation and is preserved with all proper precautions, it may deteriorate in storage due to the energy re-

³⁶ J. M. Kelly, "Radioisotopes in Pharmaceutical Research and Development," *Atomic Energy in Industry*, 3rd Annual Conference, October 13-15, 1954 (New York: National Industrial Conference Board, 1955).

³⁷ *Ibid.*

³⁸ "Labeled Compound Suppliers," *Nucleonics*, XIII (1955), No. 12, pp. 80-84.

leased by the radioactive emission. Compounds with unstable bonds, such as acetylcholine, deteriorate rapidly. The number of molecules lost or degraded by virtue of carbon-14 transmuting to nitrogen-14 can be computed to be but a negligible fraction of the total present.³⁹

The number of ways in which isotopes can be and have been used for physiological studies are legion as witness the numbers of papers dealing with the thyroid and iodine metabolism, which is only one small section of physiology. One of the more imaginative researches may be described as an illustration of the uses to which a radioisotope can be extended.⁴⁰

When a muscle contracts, there occur electrical, chemical, mechanical, and interdependent thermal changes which must be accounted for, but the relations are obscure despite the fact that some of the best men in physiology, such as A. V. Hill, Fenn, Hodgkin, Huxley, and Mommaerts, have worked on the problem. In the present report, a turtle heart was enriched with potassium-42 and then made to contract very slowly under conditions such that the fluid perfusing the heart could be collected and analyzed with reference to the mechanical and electrical changes. Upon correcting for dead space and rate of flow in the collecting system, it was proved that potassium-42 is released in a pulsatile fashion from heart muscle into the capillaries and that the peak coincides with the latter part of the T-wave of repolarization. This observation in itself is interesting, but most important is the fact that it represents experimental evidence for the movement of sodium plus and potassium plus through the cell membrane as deduced mathematically from transmembraneous electrical measurements.

In summary, it may be said that radioisotopes are an extremely promising means of increasing efficiency in the diagnosis and treatment of many diseases and of deepening understanding of the life processes of men and animals. The medical profession is

³⁹ R. M. Lemmons, "Radiation Decomposition of Carbon-14 Labeled Compounds," *Nucleonics*, XI (1953), No. 10, pp. 44-45.

⁴⁰ W. S. Wilde, J. M. O'Brien, and I. Bay, "Time Relation Between Potassium-42 Outflux, Action Potential and Contraction Phase of Heart Muscle as Revealed by the Effluogram," *Peaceful Uses of Atomic Energy: Proceedings of the International Conference in Geneva*, Vol. 12 (New York: United Nations, 1955), 318-23.

so impressed with the practical results already gained and with the numerous opportunities for further research with radioisotopes that it is calling for a new emphasis on fundamental investigation of biomedical phenomena. The consensus among medical scientists is that advances in diagnosis and therapy may be limited only by the numbers of trained men available and equipped to pursue research with radioisotopes.

PART TWO

NUCLEAR DEVELOPMENT AND PUBLIC HEALTH⁴¹

Nuclear energy is rapidly becoming a major concern in public health as well as in medicine. As nuclear industry develops, the public must learn to live safely with it, just as it has learned to live with other forms of industry, with transportation, machinery, and processes which involve potential dangers. The unfamiliar conditions of nuclear industry must be clearly understood by the public, government officials, regulatory bodies, and industry itself if the industrial applications of nuclear energy are not to be impeded. The industry must be allowed the freedom to grow within intelligently planned safeguards.

Because the initial emphasis in the development of nuclear energy was related to military efforts, major responsibility in this area was originally invested in the federal government. As peaceful uses become more important and integration into our existing economy advances, reconsideration of federal-state relationships, as well as of the role of federal agencies other than the Atomic Energy Commission, becomes necessary. As the McKinney Report remarks, "Federal, state and local authorities must continue to cooperate closely in the establishment and enforcement of the best uniform radiation health standards which can be developed. There must be balance between the conceivable and the actual hazards, however, and for some years to come the federal

⁴¹ This section and that on "Implications for Medical Education" were prepared by Clinton C. Powell, M.D., Special Assistant for Radiological Health, Division of Special Health Services, U. S. Public Health Service.

government will certainly have the responsibility of establishing this balance. This is not the sole responsibility of the Commission, but a joint responsibility of all federal agencies involved or affected."⁴²

Additional discussion of the regulation of radiation exposure by legislative means is to be found in Handbook 61 of the National Bureau of Standards, *Regulation of Radiation Exposure by Legislative Means*. Pages 1 to 26 of this handbook contain a discussion of the philosophy of radiation protection regulation which is so basic to any consideration of this problem that it is required reading for those contemplating action. This handbook also contains a suggested State Radiation Control Act and suggested regulations. It must be emphasized again that any legislation needed to accomplish the objective of the protection of the public health from ionizing radiation should be based on the need of the state involved. In many cases basic authority may already be contained in existing legislation and may require only minor modification to make implementation practicable. The uncertainty as to what constitutes safe levels of radiation exposure makes wide flexibility of paramount importance.

Potential Health Hazards

In any consideration of the potential health hazards related to the peacetime use of nuclear energy, sharp distinctions should be made between the acute and chronic effects of radiation exposure. Acute effects result from very large exposures which can be expected only in the event of a serious accident. The symptoms of acute exposure appear within a few days or weeks and, with the safeguards now employed, should be known immediately if they occur.

The effects of chronic low-level exposure, however, are more insidious and may represent a much more significant public health problem. The minimum exposure levels at which significant biological effects of such low-level exposures may be found have not yet been established with complete accuracy. The currently used "maximum permissible exposure levels" are tentative

⁴² *Peaceful Uses of Atomic Energy*, I, 128.

and based on the available information, which in many cases is inadequate.

The harmful effects may be delayed for many years, even as long as twenty to thirty years, after the exposure. Because of this time lag before symptoms begin to appear, people may conceivably suffer irreparable damage long before it is in any way apparent.

Furthermore, the most likely results of chronic exposure to radiation, such as an increase in the incidence of cancers, including leukemia, and shortening of the life span, do not differ from disease conditions already prevalent in the population, and thus a relatively large number of such cases could easily go undetected unless special attempts were made to find them.

An excellent discussion of the concept of acceptable radiation risks is contained in Handbook 59 of the National Bureau of Standards, *Permissible Dose from External Sources of Ionizing Radiation*. The following quotations summarize this concept:

It is . . . necessary to assume that any practical limit of exposure that may be set up today, will involve some risk of possible harm. The problem then is to make this risk so small that it is readily acceptable to the average individual; that is, to make the risk essentially the same as is present in ordinary occupations not involving exposure to radiation. . . .⁴³ Permissible dose may then be defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime.⁴⁴

The recent reports on the biological effects of atomic radiation published by the National Academy of Sciences-National Research Council, place considerable emphasis on the genetic hazards of radiation and indicate the importance of this problem when exposure of large population groups is involved. The subcommittee which prepared the reports on the genetic effects of radiation make the following recommendations:

- (I) Records should be kept for every individual, showing his total accumulated lifetime exposure to radiation.

⁴³ *Permissible Dose from External Sources of Ionizing Radiation*, National Bureau of Standards Handbook No. 59 (Washington: Government Printing Office, 1954), 21.

⁴⁴ *Ibid.*, 27.

- (II) The medical use of X-rays should be reduced as much as is consistent with medical necessity.
- (III) The average exposure of the population's reproductive cells to radiation above the natural background should be limited to 10 roentgens from conception to age 30.
- (IV) The 10 roentgen limit should be reconsidered periodically with a view to keeping the reproductive cell exposure at the lowest practicable level.
- (V) Individual persons should not receive a total accumulated dose to the reproductive cells of more than 50 roentgens up to age 30 years, and not more than 50 roentgens additional up to age 40. (About half of all U. S. children are born to parents under 30, nine-tenths to parents under 40.)

Other recommendations of general interest are:

- (VI) Techniques for monitoring world-wide fall-out should be further improved.
- (VII) Measurements of the storage of radiation in the stratosphere should be continued and extended.
- (VIII) A national agency should control and keep records of all dumping of radioactive material in the ocean.
- (IX) An international body should set up safe standards for the marine and air disposal of radioactive materials as soon as possible, based on current knowledge.
- (X) Research in marine disposal should be carried out on a cooperative international basis.
- (XI) Until advances in reactor technology substantially reduce potential hazards buildings that house reactors located near populated areas should be sealed against the release of radioactive materials in the event of accident.
- (XII) Research should be continued and accelerated, particularly in the fields of:

Fundamental genetics, mammalian genetics, human and population genetics

Pathological effects of radiation

Mixing between various parts of the atmosphere

Mixing between various parts of the ocean

The role of plants and animals, both on land and in the oceans in concentrating radioactive materials

The tolerable levels of radioactivity in human and animal food

Geophysical and geochemical aspects of the ultimate disposal of radioactive wastes

Selection of biologically suitable sites for various atomic facilities

Safety devices for the control of accidental power surges in reactors.⁴⁵

Particular attention is directed to recommendations I and III. Recommendation III suggests an exposure level for the general population which is appreciably below the currently established standards in use for occupational exposures but is not at wide variance with the recommendations of the National Committee on Radiation Protection. These latter recommendations state, in part: "At present the number of persons occupationally exposed to radiation is very small in comparison to the total population of the country, and therefore the dose per individual of the whole population is correspondingly small. Thus genetic damage to the population as a whole in future generations from occupational exposure is not now a limiting factor. It may become necessary later to impose further restrictions on the exposure of persons in the reproductive age, in terms of a maximum accumulated dose rather than a weekly dose."

Recommendation I of the National Research Council report concerning radiation exposure records has been discussed at some length by various groups in planning sessions and meetings of the technical panels of the SREB Work Conference. The suggestion is not original with the National Academy of Sciences-National Research Council group but has been advocated for some time. Brief discussions have pointed to the practical difficulties involved, and the committee of the National Academy of Sciences which made this recommendation considered the technical details of accomplishing this recommendation beyond its scope. The pros and cons, practicability, and usefulness of such a register should be studied.

The NAS-NRC Summary Report in its discussion of shortening of the life span makes the following comments: "Shortening of life span may result from exposure to radiation not only as a

⁴⁵ *The Biological Effects of Atomic Radiation: Report to the Public* (Washington: National Academy of Sciences-National Research Council, 1956), 7-8.

consequence of damage to a specific tissue, as seen in the development of skin cancer and leukemia, but also as a result of such general factors as lowered immunity, damage to connective tissue, or premature aging. Older members of the populations seem to be more sensitive to this non-specific damage. The shortening of life correlates roughly with dose of radiation, but has not yet been demonstrated at low doses."⁴⁶

As with all exposures to radiation it is necessary to balance the potential benefit against the presumed risk. The major problem arises in that the risk cannot yet be defined with the desired accuracy. In many areas of daily activity a significant risk is commonly accepted. Public attitude in this regard is the result of an evolutionary process. It must be remembered that the public does not accept risks from radiation in the light of objective comparison with risks from other hazards. As pointed out above, the radiation risk, when one is concerned with low-level chronic exposures, is insidious, and some fear of the unknown undoubtedly is reflected in the current public attitude. An additional concept is contained in the Summary Reports of the NAS-NRC as follows:

The use of atomic energy is perhaps one of the few major technological developments of the past 50 years in which careful consideration of the relationship of a new technology to the needs and welfare of human beings has kept pace with its development. Almost from the very beginning of the days of the Manhattan Project careful attention has been given to the biological and medical aspects of the subject. By contrast, the automobile revolutionized our pattern of living and working, but we are only now beginning to appreciate the problems of safety, urban congestion, nervous tension and atmospheric pollution which have accompanied its development. In the same way, the development of the aircraft industry outran our knowledge of how to meet the environmental needs of the human beings it intended to transport through the skies.⁴⁷

Handbook 59 of the National Bureau of Standards has been prepared primarily for the purpose of establishing standards to be used in occupational exposures, and its specific recommendations are to be found in Rules I through V on pages 61-73. Any

⁴⁶ *Ibid.*, 34-35.

⁴⁷ *Ibid.*, iii.

consideration of the potential health hazards of individuals occupationally exposed to atomic energy must take place in the context of, first, the radiation exposures already encountered by this group from medical applications such as the use of X-rays and radium and, secondly, the necessity for freedom of professional decision when serious decisions involving potential or actual saving of life are involved. The control of industrial occupational exposures to a point where essentially all employees receive radiation doses far below those recommended by the National Committee on Radiation Protection is technically feasible and has largely been accomplished in the atomic industry to date.

As private industry assumes a more prominent role in the peacetime applications of atomic energy, economic factors increase in importance, since the provision of necessary protective structures and equipment can represent a major item in the cost of operations. Because the cost of adding protective measures may be almost prohibitive, once the construction of facilities is under way, it becomes necessary to make early decisions regarding the extent to which such protective measures are to be employed in a given installation.

Along with the desirability of extensive and costly protective measures, one must consider the possible limitations of the benefits which might be imposed by economic factors as well as the increasing significance of relatively low-level exposures as the number of individuals involved increases. In other words, it is necessary to make a decision as to when funds applied for radiation protection have reached a point of significantly diminishing returns.

Over the course of many years medical and para-medical personnel have been exposed to increasing radiation hazards related to the care of patients. There have been unfortunate examples of the harmful effects of long-term radiation exposure among these people. For example, there are recent reports indicating an increase in the number of congenital abnormalities in the offspring of radiologists as compared to other medical specialists. Interest in these problems has received a healthful stimulus as a result of the expanding atomic energy industry. Increasing attention is deservedly being given to the significance of medical radiation exposures to patients. Here the potential hazards, if any, must be

carefully balanced *individually and in each case* against the possibly life-saving gain to be realized.

Biological effects of radiation are independent of the source. The potential damage to individuals requires an evaluation of their total radiation exposure whether occupational, non-occupational, or that resulting from natural background. A degree of radiation exposure results from the presence of natural radioactive substances in the environment, such as radium and radioactivity. This exposure must be accepted and is presumably beyond man's control. Current evidence indicates that medical and dental uses constitute the largest single source of radiation exposure to the general population. Currently available data do not allow accurate estimates of this exposure. The many papers which have appeared in the recent medical literature recognize the weaknesses in the data and attempt to compensate for them by the use of certain assumptions which almost certainly are not all correct.

After exhaustive study the NAS-NRC Committee on Genetic Exposure made the following statement:

Man is at present receiving radiations from the following:

- 1) *Background Radiation*—This is the radiation which results from natural causes (cosmic rays, naturally occurring radium, etc.) not under our control. Each person receives on the average a total accumulated dose of about 4.3 roentgens over a 30-year period. At high altitudes this dose is greater, because of the increase of cosmic rays. Thus, this background is as high as 5.5 roentgens in some places in the United States.
- 2) *Medical X-Rays*—According to present estimates, each person in the United States receives, on the average, a total accumulated dose to the gonads which is about 3 roentgens of X-radiation during a 30-year period. Of course, some persons get none at all, others may get a good deal more.⁴⁸

It is likely that careful study would indicate means by which medical and dental exposures could be reduced without adversely affecting medical care. The primary responsibility for determining whether each individual exposure is, in fact, warranted by medical necessity is that of the physician or dentist.

⁴⁸ *Ibid.*, 21.

The traditional patient-physician relationship has an extremely important bearing on the control of medical and dental radiation exposures to patients.

There has been loose discussion concerning the hazards related to fall-out from nuclear weapons testing. The NAS-NRC Summary Reports contain the following comments in this regard:

The Atomic Energy Commission is doing a technically competent and socially conscientious job of measuring fall-out; but it does not follow from this that one can answer, with high precision, all questions about the biological risks involved. . . . Beside those just mentioned, there are certain further uncertainties in the fall-out values. The measurements are necessarily taken far apart, and there is known to be considerable local variation due to meteorological conditions and topography. The radioactive dust, when it settles out of the air, is subject to weathering, as when it is washed off of buildings by the rain and carried to locations where it may affect fewer persons. Also individuals inside houses, or other shelters, will be considerably less exposed than those in the open air. Thus one cannot expect the figures on fall-out to be very precise ones. We have been informed that the AEC scientists are confident that the actual true dose figures are less than five times their stated estimates, and are also greater than one fifth of these stated estimates. It should be noted that the figures on fall-out as stated by the Atomic Energy Commission make only a conservative correction for weathering and shelter; and thus their figures, at least in regard to this point, tend to overstate the danger rather than the opposite.

With these understandings, it may be stated that U. S. residents have, on the average, been receiving from fall-out over the past five years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about *one-tenth of a roentgen*; and since the accuracy involved is probably not better than a factor of five, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.22 roentgens and smaller than 0.50 roentgens.

The rate of fall-out over the past five years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred in (1953 and 1955) then the 30-year fall-out dose would be about twice that stated above. The dose from fall-out is roughly proportional to the number of equal sized weapons exploded in air, so that a doubling of the test rate might be expected to double the fall-out.⁴⁹

⁴⁹ *Ibid.*, 21-22.

The problem of non-occupational exposure resulting from industrial uses (exposure of the public as a result of industrial applications) of nuclear energy is of primary concern to health agencies. As mentioned above, this exposure may be either an acute exposure, as a result of accidents, or chronic low-level exposure, primarily resulting from waste and by-product disposal. If one postulates the worst possible set of circumstances, the results of a major accident, particularly where a nuclear reactor is involved, could be serious in terms of acute radiation injury to a large number of people outside the actual reactor site. Proper safeguards, particularly in design and site selection, should reduce the possibility to a minimum, although not absolutely to zero. The technical problems involved are not insurmountable, but the cost factors are considerable. Of equal importance so far as the Public Health Service is concerned are the problems relating to the less dramatic accidents, such as the turning of the wrong valve, which might inadvertently release highly radioactive material to the environment, although not of a level sufficient to cause immediate or widespread injury.

Radioactive Waste Disposal

The problem of waste and by-product disposal from industrial installations is a major practical and economic one affecting the widespread applications of nuclear energy. An excellent summary of the present status of this problem is to be found in the NAS-NRC Summary Report, as follows:

1. The safe handling and ultimate disposal of radioactive wastes is an important technical, economic and administrative aspect of the nuclear energy industry. Waste operations must be thoroughly integrated with all other phases of nuclear energy operation.
2. From a technological standpoint the highly radioactive wastes resulting from the processing of reactor fuels constitute the bulk of the problem. To date essentially none of those wastes has been disposed of, i.e., returned to the environment. Tank storage is presently utilized as an interim answer to this problem.
3. Wastes resulting from normal reactor operations are an im-

portant consideration, but technically represent a problem for which solutions are generally available.

4. Research and development have indicated possible feasible systems of ultimate controlled disposal of highly radioactive wastes, but considerably more work is required to bring these systems to the point of economic operating reality.
5. Major technical and economic considerations underlying the waste problem are:
 - a. Characteristics of nuclear fuels and chemical (or other) processing associated with them.
 - b. Separation of specific isotopes from the wastes and use of these materials to economic advantages.
 - c. The proper selection of the site for nuclear facilities—especially reactor and fuel processing plants.
 - d. The detailed quantitative evaluation of the environment in order to assess its capacity to receive radioactive materials without creating deleterious effects on the environment.
 - e. Systems for the physical handling and transportation of highly radioactive materials.
6. Major policy and administrative considerations relevant to the regulation of the waste problem are:
 - a. The establishment, perhaps through private enterprise, of suitable waste disposal services.
 - b. The regulation and control of waste disposal practices through existing and traditional state, interstate and local channels where feasible.
 - c. Continuation and strengthening of established practices in relations with the public and its agencies.⁵⁰

Practical methods of disposal of smaller quantities of radioactive waste, which provide a reasonable solution to the problem in the medical field, are to be found in Handbooks 40 and 53 of the National Bureau of Standards.

Applications of Discoveries in Nuclear Medicine

The importance of radioisotopes in medical research, particularly in basic research, has already been pointed out, and the status report of medical applications which follows reviews the uses in some detail. Better understanding of basic biologic processes in the normal individual and their derangements in disease

⁵⁰ *Ibid.*, 101-103.

is proving valuable in disease control programs. As the traditional activities of health departments, particularly control of communicable diseases, have become less important, health departments have assumed responsibility for the control of what are ordinarily classed as "chronic" diseases. Increasing emphasis on the federal level has been based on research and control of these chronic diseases, although the emphasis of state health departments in this field varies widely.

With the increased interest of public health organizations in the ultimate control of such conditions as heart disease and cancer has come a need for more basic information on which sound control programs can be built. It is thus apparent that many of the advances which have been discussed in the section on medical applications will benefit the field of public health.

Radioisotopes have also become increasingly important as an investigative tool in environmental sanitation and sanitary engineering. Radioisotopes as tracers have shown the practicability of a number of new techniques useful in the design of water and sewage treatment plants and in the investigation of self-purification of waste in streams and soils. Knowledge of the effects and mechanisms of dilution factors in streams into which human and industrial wastes are introduced has allowed more accurate definition of the limitations of the dilution technique for waste disposal. Investigations have been conducted into the mechanisms and effectiveness of sand filtration methods for the purification of water and sewage.

The results of investigations to date indicate that in certain cases the currently standard methods of water analysis can also be improved by the use of radioactive tracers. Isotopic methods for the determination of chloride and sulfate ions in drinking water point to the possibility of much more rapid and appreciably simpler tests than those now being used. It may be anticipated that isotope techniques will be developed, making possible rapid tests for contamination which are much more sensitive and easier to perform than those currently used.

Radioactive tracers help in the determination of hydraulic flow problems related to the design of water and sewage treatment plants and also to dynamic flow problems within sewage collection and water distribution systems. In addition, many of the

common industrial uses of radioisotopes, such as wear and corrosion studies and industrial radiography, are of indirect benefit to sanitary engineering.

In the same way that problems in hydraulic engineering are being solved, methods for the control of air contamination are being advanced by the use of isotope techniques. For example, they are useful in the study of air circulation, concentration, and dilution problems, as well as of problems related to absorption and physiological importance as a function of particle size.

IMPLICATIONS FOR MEDICAL EDUCATION

Many physicians in practice today were educated before the medical use of radioisotopes became an actuality. Many physicians using X-ray equipment in their daily practice today likewise received their formal training before the potential hazards of radiation became as well understood as they are now. It seems obvious that some means for bringing this newer knowledge to this group, either for their personal use or to provide the knowledge on which they can base referral to others, is indicated. Traditional techniques of postgraduate medical education offer methods for accomplishing this objective.

As for physicians entering practice today the McKinney Report states, "... for the most part, American medical and postdoctoral students today are going into practice without any real knowledge of the general effects of radiation or the techniques made possible by the availability of radioisotopes . . . only 870 hospitals and clinics out of 6,970 have radiation and radioisotope handling facilities today. Roughly half the medical schools in the country have no facilities to aid in teaching these techniques to their students. . . .⁵¹

With respect to applications of nuclear energy, the manpower bottleneck is just as acute in the health sciences as it is in other fields. The reasons for this are varied and poorly defined and would carry little weight in formal debate; however, though ridiculous as evidence, it is nevertheless true that most medical

⁵¹ *Peaceful Uses of Atomic Energy*, I, 59-60.

students turn off their minds when an instructor writes a mathematical formula on the board. Also, most individuals in the medical profession will accept clinical impressions as readily as scientific data, for they recognize that the practice of medicine associates closely with the art of medicine. It is as if when they turned to medicine, they turned their backs on physics. Earlier there was considerable interest in the profession when it appeared that radioisotopes might enlarge the therapeutic armamentarium, but now that the outlook for "miracle cures" has dimmed, there remains only a small core in the profession which looks on nuclear energy as an object intrinsically worth study.

These dedicated individuals will be found in every branch of medicine, clinical and pre-clinical, but the majority are radiologists or internists. The radiologists have taken the first formal steps toward identifying themselves with nuclear energy by requiring that future certifications of the American Board of Radiology will require what is called Nuclear Medicine. In order to qualify for the specialty, beginning in 1956, they must stand examinations which will include optional questions on nuclear energy and nuclear medicine. They will be strongly urged to answer those questions in the next three examinations, and in 1960 the questions will be mandatory.

At the convention of the American Medical Association, in June, 1956, the chairman of the section on General Practice suggested that the physician, and especially the general practitioner, needed to be better acquainted with all aspects of nuclear energy, in view of the physician's responsibility to the public in the event of a disaster or hazardous conditions from tests or accidents and in view of the growing use of isotopes in industry. He noted that there was a large mass of data on isotopes and radiation effects which ought to be passed along to the profession, piece by piece, because it simply could not be digested *en masse*.⁵² He blamed this accumulation on security regulations. While this view on security is believed to be inaccurate, it is noted as an example of the uncertainty which exists in the profession and which

⁵² I. Phillip Frohman, "The Role of the General Physician in the Atomic Age," Chairman's Address, Section on General Practice, American Medical Association, Chicago Meeting, June 11, 1956.

will influence efforts toward establishing educational facilities in medical institutions in the field of nuclear medicine.

Dr. Charles Dunham, Director of the AEC Division of Biology and Medicine, recently said,

A few years ago only a relatively few persons, radiologists and a small number of physicists, were in a position to be injured by radiation. But now the ever-growing atomic energy industry has swelled this number to many thousands. Although remarkably few radiation injuries have been recorded to date in spite of the rapid expansion of this work and the fantastic quantities of radioactivity handled today, it is absolutely essential that every physician and medical student become conversant with the biological effects of ionizing radiation and the diagnosis and treatment of the various types of radiation injury in both their acute and chronic or late manifestations. This is important not only so that the physician can recognize and give appropriate treatment for radiation injury when it occurs, but also in order that he can reassure his patient that his symptoms are not due to radiation if indeed no overexposure has occurred.⁵³

The formal medical and premedical training of a physician does not predispose him toward a field related to physics. The requirements in physics usually amount to about twelve hours, or about half the time for either chemistry or biology-psychology.⁵⁴ Only a few students who major in physics go on into medicine. In medical school one takes a fourteen- to sixteen-hour course in physiology and, as often as not, it is taught from a biochemical point of view. Student training in the use of radioisotopes in medical schools is apparently on an individual basis, according to the McKinney Report.⁵⁵ A survey revealed that only fifteen of eighty schools contemplate introducing the subject as an integral part of their curricula. This survey also showed that thirty-five of the eighty institutions gave no time at all to the field and only twenty-seven of the eighty devoted more than ten hours to the

⁵³ Charles L. Dunham, "The Impact on Atomic Energy Activities of Medicine and Medical Research," speech before 10th Annual Rocky Mountain Cancer Conference, Denver, Colorado, July 12, 1956.

⁵⁴ H. D. Bruner, "Physics and Medical Research," A.A.A.S. Symposium on the Role of Physics in Premedical Education, Atlanta, Georgia, December 28, 1955.

⁵⁵ *Peaceful Uses of Atomic Energy*, II, 138.

subject over the entire four years. Medicine and radiology did most of the instruction; surgery was a poor third; and very small amounts were scattered in the basic sciences. The basic science departments of many schools offer instruction in special graduate courses or preceptorship training in the use of radioisotopes for research, but the medical student rarely has an opportunity to go outside the fixed curriculum.

In order to qualify for an allocation of radioisotopes, the practicing physician in the past has had to undergo a long preceptorship. He had to participate in an already established diagnostic-treatment program until the director of the section was willing to support an application for allocation. His application was then considered by the Subcommittee on Human Applications of the Atomic Energy Commission's General Advisory Committee on Isotope Distribution. Many feel that the Subcommittee has been too conservative; however, they have carried out their assignment conscientiously within the legal requirements of the Atomic Energy Act. With time and experience the requirements have become somewhat more liberal and less formalized with respect to stated uses by the prospective user.⁵⁶

The preceptorship system offered no great problem for physicians in cities, as they could arrange their practice to attend clinics and teaching sessions on a definite schedule; however, the physician at an appreciable distance from a large medical center was not able to arrange such a schedule except under unusual circumstances. The result has been that an ample supply has been trained in the larger cities, with slow or no diffusion of trained individuals into the small town and rural areas. Consequently, patients in the larger cities have had relatively easy access to isotopes, whereas those in the less urban and rural areas have found referral to the city impossibly expensive.

The obvious alternative to this cumbersome preceptorship system is the formal course which would satisfy the criteria established by the Subcommittee. The best course would be one designed specifically for medical students in their junior or senior year, but this seems to be something for the future. Similarly,

⁵⁶ "The Medical Use of Isotopes: Recommendations and Requirements by the Atomic Energy Commission," Isotopes Division, Atomic Energy Commission, Oak Ridge, Tennessee, May, 1955.

training for residents, except in radiology and hematology, will probably be sketchy. Given time and impetus from without, however, this needed course work will undoubtedly be set up.

Courses for practicing physicians should not necessarily attempt to provide the training and experience relating to all uses of all radioisotopes. For example, a course might be designed to qualify the physician to measure plasma volume or use iodine-131 for diagnosing thyroid conditions. On the other hand, work dealing with therapeutic uses would require a longer time because of the necessity of follow-up on the patient's response. There is no reason why the physician cannot acquire radioisotope experience step by step, except that he becomes impatient. The recent acceptance of solutions of phosphorus-32 and iodine-131 into the U. S. Pharmacopeia may accentuate his feeling of being improperly restricted.

Medical schools, hospitals, and the Atomic Energy Commission have been noticeably hesitant in offering courses specifically for the practicing physician in this field. This is so perhaps partly because the course could not guarantee approval to procure isotopes and partly because no format could be designed that would satisfy all the conflicting factors and interests.

Through the courtesy of the Isotopes Extension of the Division of Civilian Applications of the AEC, a list of fifteen courses on various phases of the clinical use of isotopes was examined. These courses varied in length from one week to a full residency, and the sessions varied from continuously for one to two weeks to several months at weekly intervals. Twelve of the fifteen were connected with university hospitals, where either the university or the hospital department or both were very active in radiology or research on radiation. It would appear that a course develops only where there is a strong interest in radiation on the part of the institution or on the part of an individual interested in teaching such a course. All, unfortunately, are in large centers of population. There are none in the South at present, although Emory University gave one such course in 1953.

The small number of courses and their irregular schedule suggest that few institutions are convinced that such efforts are presently legitimate educational efforts. Why should a school undertake isotope courses on a large scale when they are already

overburdened and their finances strained? Who will pay for this teaching is a question that underlies every discussion on isotope training in medical institutions.

If more physicians are to use radioisotopes, a way must be found to provide courses and material in locations closer to their homes so that they will not be completely cut off from their practice too long. Also because they cease to earn while engaged in postgraduate work, a subsidy of some sort would materially strengthen their desire for such training. The same reasoning applies to the training of nurses and technicians who must aid in caring for the radioactive patient.

Although a few medical schools could quickly develop an effective isotopes course if sufficiently urged, there is still another aspect of the task which needs the services of a public information group. With proper organization the various groups interested in nuclear energy could more effectively work together and support one another. As matters stand at present there is no over-all plan or program to coordinate efforts.

As is noted later, there is a clear trend from the "try it out on a large group" type of study to the slow experimentation by an individual with an original idea. Because the latter can be carried out on a lab bench as easily as in the most spacious modern laboratory and because it is relatively inexpensive, the simple experiment often is discounted as being of little merit. The fact that it is modest does not necessarily detract from its scientific significance. Perhaps the research grant agencies should be urged to set aside more funds for "venture experiments" than they have in the past.

Since there are fewer graduate students and post-doctoral fellows than there are fellowships, it will be hard to entice good men into this field without attaching a more realistic stipend to the grants. As stated in the McKinney Report,

The Atomic Energy Commission fellowships are now limited to the field of health physics, industrial medicine, and industrial hygiene. Heretofore general postdoctorateship fellowships were offered by the AEC; however, these have been discontinued and a partial substitute has been provided by authorization to the National Science Foundation to grant postdoctorateship fellowships which may cover techniques involving atomic energy. The stipends in both the Atomic Energy Com-

mission fellowship program and the National Science Foundation fellowship program are essentially nominal and in experience have not proven sufficiently attractive to become a useful mechanism for stimulating entry into the field of applications of atomic energy to medicine.⁵⁷

The final conclusions and recommendations of the McKinney Report in the field of medicine are valid for the South as much as for any other region. They are reproduced below:

1. Provide all medical schools with adequate facilities for training in atomic medicine techniques;
2. Create additional research centers with all appropriate equipment, including reactors;
3. Design low-cost atomic medical equipment suitable to the needs of the 6,100 hospitals and medical clinics without atomic facilities and provide at least minimal facilities to this group as rapidly as possible;
4. Make available at reasonable prices the now-expensive radioactively labeled organic compounds essential for research and therapy;
5. Assure prompt availability of current atomic developments in the field of medicine and medical research, with opportunity for full interchange of latest data and without reference of the independence of medical research investigators and
6. Inaugurate a nationwide educational program on the more judicious use of radiation and the need for better record-keeping of the exposure of individuals to radiation from all sources.⁵⁸

PROPOSED REGIONAL AND STATE ACTION

The SREB Work Conference concluded that the most urgent need facing the region in its effort to foster the applications of nuclear energy in medicine and public health was for an information center with consultant services. The Work Conference recommended that such a center be established within the framework of an existing regional agency. The center would have three

⁵⁷ L. H. Hempelmann and S. Warren, "Atomic Energy in Medicine," in *Peaceful Uses of Atomic Energy*, II, 141.

⁵⁸ *Peaceful Uses of Atomic Energy*, I, 61-62.

functions: (1) to collect and disseminate information about sources, opportunities, and funds which would help expand nuclear medicine; (2) to help prepare and submit applications for grants-in-aid for support of research, teaching, and training in all aspects of nuclear medicine; and (3) to make sure that Southern facilities in nuclear medicine meet and lead national standards.

The Work Conference recognized that expansion of centers for the treatment of disease by nuclear energy depends on the interests and drive of personnel surrounded by the best possible working conditions. These must be tailored to fit individuals whose interest in the field is ordinarily generated by contact with radioactive materials during training as student, intern, and resident. Their contact with radioactivity should be under excellent conditions, not the least of which is enthusiastic teaching. The Work Conference recommended, therefore, that some existing agency inquire into and publicize all courses, both formal and informal, available and projected in the region, which contribute to the training of medical and paramedical personnel in nuclear medicine.

Since an appreciable number of medical students are drawn from small colleges, the Work Conference felt that it is essential that their science courses, expensive as they are, receive both academic and financial support and stimulation. It was also noted that the average medical student, regardless of his preparatory school, is deficient in mathematics and physics, the two disciplines which lead naturally to interest in radiology and nuclear medicine. Accordingly, the Work Conference recommended that special attention be given to stimulating the educational and research potentials of the numerous small colleges of the region.

With regard to nuclear applications in public health, the Work Conference took the position that training needs should be more clearly defined than they are at present. In order to expand training facilities economically, the Conference felt that a survey should be made first to disclose the location and adequacy of present training facilities, to point up areas needing attention, reveal any unnecessary duplication of effort, and indicate areas where new industries and government agencies might expect to obtain training for employees. The Work Conference recom-

mended that such a survey be made by an existing agency and that the results be publicized to all the states in the region.

The Work Conference believed that no new state agencies are needed to handle the problems arising from nuclear developments. It recommended that responsibility for health and safety as related to nuclear energy be clearly delegated to whatever state agency is normally responsible for the public health. This recommendation was based on the fact that a core of public health personnel already exists in each state and therefore duplication of effort and resources would be avoided. The Work Conference was also concerned that nuclear industry should be provided with only one set of official radiological health regulations developed by one agency, thus preventing confusion.

Pending the survey described above, the Work Conference recommended the establishment of adequate training facilities in each state to relieve the shortage of radiological health specialists. Teaching staffs, adequate plant, research and training reactors, and other radiation sources would be required. The Work Conference further recommended that the U. S. Public Health Service and other agencies increase the opportunities they offer for short course training for state and local public health personnel and assist state health departments in developing their programs.

The Work Conference was impressed with the fact that the long-term effects of radiation exposure on human beings are not sufficiently understood to permit definite conclusions. Many thousands of detailed records of individuals, requiring perhaps such entries as the results of physical examinations as well as the number and degree of radiation exposures, must be accumulated before it will be possible to determine accurately the long-term effects of radiation. Background radioactivity varies from place to place, and the Work Conference thought it important to monitor and keep records of findings in each area. If a nuclear industry were established in a given area, it should be possible to determine any changes in the type and degree of radioactivity. In the event of an increase, appropriate controls could be set up. Such monitoring would have the incidental value of training people throughout the Southern states in a procedure which could be widely applied in the field of radiological safety. For these reasons the Work Conference recommended that pilot

studies be undertaken by state health agencies and the U. S. Public Health Service to select the best methods for keeping individual records of exposure to radiation and that each state be encouraged to study background radiation within its borders and make careful, permanent records.

Finally, the Work Conference recommended that a survey be made of research facilities in each state in order to find out what they might contribute to the development of realistic limits and standards for radiation exposure. Universities, non-profit research organizations, state agencies, etc., would be involved. Results of these surveys should be submitted for review to a regional group, such as the Oak Ridge Institute of Nuclear Studies, in order to avoid unnecessary duplication of effort and to stimulate needed research in the several states. The data needed to evaluate the potential hazards of radiation exposure might thus be accumulated and organized for use throughout the South in the interests of the public health.

EDUCATED MANPOWER: KEY TO NUCLEAR DEVELOPMENT¹



Neither the South nor the nation at large can now meet the demand for nuclear engineers, scientists, professional men, and technicians; if the demand increases as it is expected to do during the next few years, the region will face a serious crisis unless it contrives to increase the supply of educated manpower. The problem is the more acute because nuclear techniques provide effective new tools for research in a great many fields. These create demands for large numbers of trained people, not only in specifically nuclear areas, but throughout the sciences, industry, and government. Thus the development of nuclear power and the general application of the by-products of nuclear reactors in industry, agriculture, and medicine wait upon the production of appropriately trained people.

The colleges and universities of the South are already trying to meet the demands of the nuclear era. They are introducing new courses, expanding and modernizing old ones, and providing new laboratory and research facilities for nuclear science. Unless a major effort is begun now to solve or prevent the problems which educational institutions face in providing these services, the nuclear development of the South will be seriously handi-

¹ Chapter V was prepared by J. K. Folger, Research Associate, Southern Regional Education Board, and M. L. Meeks, Associate Professor of Physics, Georgia Institute Of Technology.

capped for lack of trained personnel. On the other hand, an adequate educational program would be one of the best ways of making sure that the South has a leading role in future nuclear developments.

SCIENTISTS AND ENGINEERS

Especially important is the education of the scientists and engineers who must plan and guide development of nuclear science and technology. The number of scientists and engineers which will be needed cannot be determined with precision, but it will be small, relative to the total number of engineers and scientists, and probably difficult to obtain. The reasons are that specialized skills are required for nuclear work and that scientists and engineers of all sorts are in short supply, a condition which will continue for several years.

In 1950 the census reported 105,000 engineers in the South and 534,000 nationally. Engineers were 0.23 per cent of the total Southern population in 1950 and 0.35 per cent nationally. The National Science Foundation estimates that in mid-1954 there were about 650,000 engineers and 200,000 scientists in the United States.² According to the McKinney Report there were about 15,000 professionally trained scientists working in the nuclear field.³ On this basis the Southern Regional Education Board estimates that there were about 135,000 engineers and 40,000 scientists in the South in mid-1954.

In the next ten years the demand for scientists and engineers will probably exceed the supply. Table 1 shows estimates of the need for engineers compared with the number of bachelor's degree graduates in engineering. The estimate of demand assumes that engineers will continue to increase as a percentage of the population at the same rate as between 1940 and 1950. The estimates of supply ignore the engineers who will enter the profession without a degree. At the present time about 40 per cent of em-

² National Science Foundation, *Scientific Personnel Resources* (Washington: Government Printing Office, 1955), 7.

³ *Peaceful Uses of Atomic Energy*, II, 551.

employed engineers have less than four years of college, and substantial numbers will undoubtedly continue to enter the profession without a degree. These figures indicate that the general shortage of engineers will probably continue for several years, although supply and demand may come into somewhat better balance in the early 1960's.

TABLE 1

PROJECTED SUPPLY OF ENGINEERS IN THE SOUTH AND U. S. COMPARED WITH PROJECTED DEMAND FOR ENGINEERS IN THE SOUTH AND U. S.

PERIOD	NEEDS (IN 1,000's)*			PROJECTED SUPPLY (IN 1,000's)	SURPLUS OR DEFICIT	SURPLUS OR DEFICIT AS PERCENTAGE OF TOTAL NEEDS
	For Growth of Profession	For Replacement	Total			
U. S.						
1950-54	188	56	244	170†	- 74	-30
1955-59	209	56	265	161‡	-104	-39
1960-64	225	60	285	199‡	- 86	-30
1955-64	424	116	550	360‡	-190	-35
SOUTH						
1950-54	37	9	46	39†	- 7	-15
1955-59	44	9	53	38	- 15	-28
1960-64	46	10	56	60	4	7
1955-64	90	19	109	98	- 11	-10

*Needs for both U. S. and South assume the proportion of engineers to total population will increase at the rate observed between 1940 and 1950. Replacement needs assume 1950 U. S. white male mortality rates, no net loss or gain to other professions, and that all engineers retire at age 65.

†Actual Degree Graduates.

‡Joint Committee on Atomic Energy, *Engineering and Scientific Manpower in the U. S., Western Europe and Soviet Russia* (Washington: Government Printing Office, 1956), 14.

The needs for scientists, especially scientists with the Ph.D., will also probably exceed the supply during the next decade. Table 2 shows the supply-and-demand picture, though with no pretense of close accuracy. These estimates show that the crux of the problem is in the supply of persons with master's and doctor's degrees. At the bachelor's level the supply should be adequate to

TABLE 2

SUPPLY AND DEMAND FOR PHYSICAL SCIENTISTS AND MATHEMATICIANS
IN THE SOUTH, 1950-1965

YEAR	ESTIMATED DEMAND FOR SCIENTISTS*	ESTIMATED SUPPLY OF SCIENTISTS †	ESTIMATED DEGREE GRADUATES		
			Bachelors	Masters	Doctors
1950-54	14,000	10,000	24,557‡	3,752‡	1,213‡
1955-59	16,000	11,000	23,000	4,000	1,500
1960-64	17,000	17,000	32,000	6,000	2,400
1955-64	33,000	28,000	55,000	10,000	3,900

*Demand is estimated on the assumption that the need for scientists will grow at the same rate as the need for engineers.

†Supply assumes that only one-half of the scientists needed may be bachelor's level (this is the present percentage), thus the supply is limited by the total output of master's and doctor's degrees.

‡Actual Graduates

TABLE 3

TOTAL ENGINEERING ENROLLMENT PROJECTIONS TO 1965-66,
SOUTHERN REGION

Year	Low Projection	Medium Projection	High Projection
1949-50	—	49,393*	—
1950-51	—	39,210*	—
1951-52	—	35,213*	—
1952-53	—	37,790*	—
1953-54	—	44,083*	—
1954-55	—	50,339*	—
1955-56	—	58,683*	—
1956-57	63,000	65,000	68,000
1957-58	65,000	70,000	76,000
1958-59	66,000	75,000	84,000
1959-60	67,000	78,000	90,000
1960-61	69,000	82,000	95,000
1961-62	73,000	87,000	101,000
1962-63	75,000	89,000	103,000
1963-64	76,000	91,000	105,000
1964-65	79,000	94,000	109,000
1965-66	85,000	100,000	116,000

*Actual data

meet the needs except in the field of high school teaching. A study made in 1952 indicated that 29 per cent of the bachelor's graduates in science the previous year were employed in jobs related to their education.⁴ If this percentage of the bachelor's graduates of the next decade is available, it should meet the needs for bachelor's level scientists. The situation at the master's and doctoral levels is much more critical.

The need for college teachers in the physical sciences and engineering will create a large demand for the Ph.D. graduates of the next decade. According to our medium projection of enrollment, there will be a 70 per cent increase in engineering enrollments in the next ten years (see Tables 3 and 4). Enrollments in science can be expected to grow in about the same proportions.

TABLE 4

PROJECTIONS OF TOTAL BACHELOR'S DEGREES IN ENGINEERING
TO 1965-66, SOUTHERN REGION

Year	Low Projection	Medium Projection	High Projection
1937-38	—	2,196*	—
1947-48	—	7,243*	—
1948-49	—	10,291*	—
1949-50	—	12,671*	—
1950-51	—	9,803*	—
1951-52	—	6,395*	—
1952-53	—	5,318*	—
1953-54	—	4,877*	—
1954-55	—	4,966*	—
1955-56	6,300	6,300	6,300
1956-57	7,700	7,700	7,700
1957-58	9,000	9,000	9,000
1958-59	10,300	10,300	10,300
1959-60	9,800	10,500	12,000
1960-61	9,400	11,100	12,900
1961-62	10,100	12,000	13,800
1962-63	10,700	12,700	14,700
1963-64	11,200	13,300	15,400
1964-65	11,900	14,100	16,300
1965-66	11,600	13,800	16,000

*Actual data

⁴ National Science Foundation, *Scientific Personnel Resources*, 17.

At present there are approximately 5,100 science teachers and 2,600 engineering teachers in colleges in the region.⁵ If the present faculty-student ratios are maintained, approximately 5,400 science and engineering teachers will have to be added in the region to take care of enrollment increases, and about 1,900 to replace teachers dying, retiring or otherwise leaving the profession, assuming an attrition of 25 per cent in ten years. This makes a total need for about 7,000 to 7,500 new physical science and engineering faculty members in colleges.

In the next ten years the schools of the region will grant approximately 4,200 physical science and mathematics doctorates (see Table 5) and 800 doctorates in engineering. In terms of past

TABLE 5

PROJECTION OF DEGREES IN MATHEMATICS AND THE PHYSICAL SCIENCES,
SOUTHERN REGION, 1948-1965

YEAR	LOW PROJECTION			MEDIUM PROJECTION			HIGH PROJECTION		
	Bachelor's	Master's	Doctor's	Bachelor's	Master's	Doctor's	Bachelor's	Master's	Doctor's
1947-48	—	—	—	4,105*	497*	81*	—	—	—
1948-49	—	—	—	5,638*	636*	134*	—	—	—
1949-50	—	—	—	6,697*	779*	177*	—	—	—
1950-51	—	—	—	5,699*	967*	224*	—	—	—
1951-52	—	—	—	4,535*	741*	234*	—	—	—
1952-53	—	—	—	3,903*	631*	272*	—	—	—
1953-54	—	—	—	3,723*	634*	306*	—	—	—
1954-55	—	—	—	4,009*	625*	285*	—	—	—
1955-56	3,900	600	300	4,200	700	300	4,500	700	300
1956-57	3,800	700	300	4,500	800	300	5,200	800	300
1957-58	4,000	700	300	5,000	900	300	6,000	1,000	400
1958-59	4,300	800	300	5,300	1,000	400	6,400	1,200	400
1959-60	4,500	900	400	5,600	1,100	400	6,800	1,300	500
1960-61	4,800	900	400	6,000	1,100	400	7,200	1,400	500
1961-62	5,200	1,000	400	6,500	1,200	500	7,700	1,500	500
1962-63	5,500	1,000	400	6,800	1,300	500	8,200	1,600	600
1963-64	5,800	1,100	500	7,200	1,400	500	8,700	1,700	600
1964-65	6,100	1,200	500	7,600	1,400	600	9,100	1,800	600

*Actual data

⁵ Estimate derived from Mary Irwin, *American Universities and Colleges* (7th ed.; Washington: American Council on Education, 1956). Estimates were made of faculty in unaccredited schools.

performance, between 30 and 40 per cent of these graduates will go into college teaching.⁶ Competition for these graduates may force the proportion down, since colleges pay lower salaries than industry or government. However, assuming 40 per cent go into college teaching, only 2,000 graduates would be available in the next ten years for the 7,000 to 7,500 vacancies in teaching which must be filled. Since slightly more than half of the college teachers of physics (60 per cent) and chemistry (55 per cent) have Ph.D.'s, these figures indicate that the proportion of teachers with doctoral degrees will decline rapidly in the next ten years or that there will be many unfilled teaching positions, or both.

The situation is already acute. In 1954 and 1955, 75 per cent of the Southern institutions reported a shortage of qualified faculty members in the physical sciences, 39 per cent reported a shortage in mathematics, and 14 per cent reported a shortage in engineering. The comparable national figures are 69, 29, and 15 per cent, indicating a slightly greater shortage in the South.⁷

If the South is to maintain the quality of its science and engineering programs and expand their size, it must compete for talent by providing better working conditions, more opportunities for research, and higher salaries. Many industrial and governmental jobs are attractive because the scientist has well-equipped laboratories to work in and assistants who free him from routine tasks. Colleges and universities have lagged in providing assistants for their professors and in providing the funds for research equipment and teaching aids. Research is essential to a good graduate program, and an institution that emphasizes research has a good advantage in recruiting faculty members. Last, and probably most important, faculty salaries must be raised if the colleges are to compete for talent. A 1955 survey of chemists revealed that a chemist in industrial research earns an average of 25 per cent more than a chemist with similar education and ex-

⁶ U. S. Bureau of Labor Statistics, *Manpower Resources in Chemistry and Chemical Engineering* (Washington: Government Printing Office, 1953), 22; also, U. S. Office of Education, *Manpower Resources in Physics, 1951* (Washington: Government Printing Office, 1952), 16.

⁷ "Teacher Supply and Demand in Degree-Granting Institutions, 1954-1955," *National Education Association Research Bulletin*, XXXIII (December, 1955), 151. Figures for Southern institutions were specially tabulated by the Research Division of the National Education Association.

perience in college work.⁸ Southern colleges, moreover, pay lower salaries than colleges in other regions, especially to their highest ranking men. Recent surveys indicate that full professors in the South earn \$1,000 to \$2,000 a year less than professors in other regions.⁹

HIGH SCHOOL TEACHERS OF SCIENCE AND MATHEMATICS

The shortage of qualified high school science teachers is likely to be even more serious than the shortage of college teachers. In the last ten years the number of students taking science has increased, but less rapidly than total high school enrollment. The proportion of students taking science courses in the South compares favorably with the national proportion in most courses (see Table 6), but these trends may be altered if the number of qualified high school science teachers cannot be increased.

In 1950 there were three graduates with teaching certificates in

TABLE 6

PERCENTAGE OF STUDENTS ENROLLED IN SCIENCE AND MATHEMATICS COURSES

COURSE AND USUAL GRADE		U. S.		SOUTH—1955		
		1949	1955	South Atlantic	East South Central	West South Central
Biology	(10th)	66.8	72.6	87.7	75.1	66.3
Chemistry	(11th)	33.2	31.9	32.8	30.8	23.6
Physics	(12th)	28.4	23.5	17.3	32.5	12.8
Elementry Algebra	(9th)	63.5	61.5	64.2	72.5	72.2
Intermediate Algebra	(11th)	32.7	28.5	37.9	36.5	45.1
General Math	(9th)	42.9	41.5	61.0	55.2	46.7
Plane Geometry	(10th)	40.2	37.4	26.4	33.6	45.7
Solid Geometry	(12th)	9.2	6.5	4.8	4.7	5.5
Trigonometry	(12th)	10.6	13.0	5.6	4.4	4.4

⁸ Andrew Fraser, "The 1955 Professional and Economic Survey of the Membership of the American Chemical Society," *Chemical and Engineering News* (April 9, 1956), 1765.

⁹ SREB survey made in 1954.

science for every two new positions; by 1955 there was only one graduate with a certificate for every two new positions (see Table 7). Sample studies show that of the graduates with certificates in science in 1954 and 1955, between one-half and two-thirds did not enter teaching at all.¹⁰ In high school science teaching in 1954 and 1955, it would appear that between one in three and one in four of the new positions were filled by newly certified teachers. Many of the others were undoubtedly filled with people who were returning to teaching and had certificates, but many of them were filled with people who did not have certificates. Dr. Maul of the National Education Association found that 40 per cent of the mathematics teaching positions were filled by people who were not qualified in mathematics.¹¹

During the next ten years, high school enrollment in the region

TABLE 7
SUPPLY AND DEMAND FOR HIGH SCHOOL SCIENCE AND MATHEMATICS TEACHERS

YEAR	U. S.*			South†		
	1 Number of New Teachers Hired	2 No. of Graduates with Certificates‡	3 Col. 2 ÷ Col. 1	4 Number of New Teachers Hired	5 No. of Graduates with Certificates	6 Col. 5 ÷ Col. 4
1950	3017	4663	1.55	1013	1353	1.34
1951	3283	3923	1.19	1408	1550	1.10
1952	2979	3128	1.05	—	—	—
1953	3821	2918	0.76	1679	1417	0.84
1954	3604	2410	0.67	1870	1251	0.67
1955	3890	2133	0.55	2167	1264	0.58

*U. S. total based on reports from 26 to 32 states, not always the same.

†South includes reports from an increasing number of states. In 1950 there were reports from Alabama, Delaware, Kentucky, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia.

‡Indicates number of graduates with a certificate to teach high school science and mathematics.

Source: "Teacher Supply and Demand Report," *The Journal of Teacher Education*, annual March issues, 1951-1956.

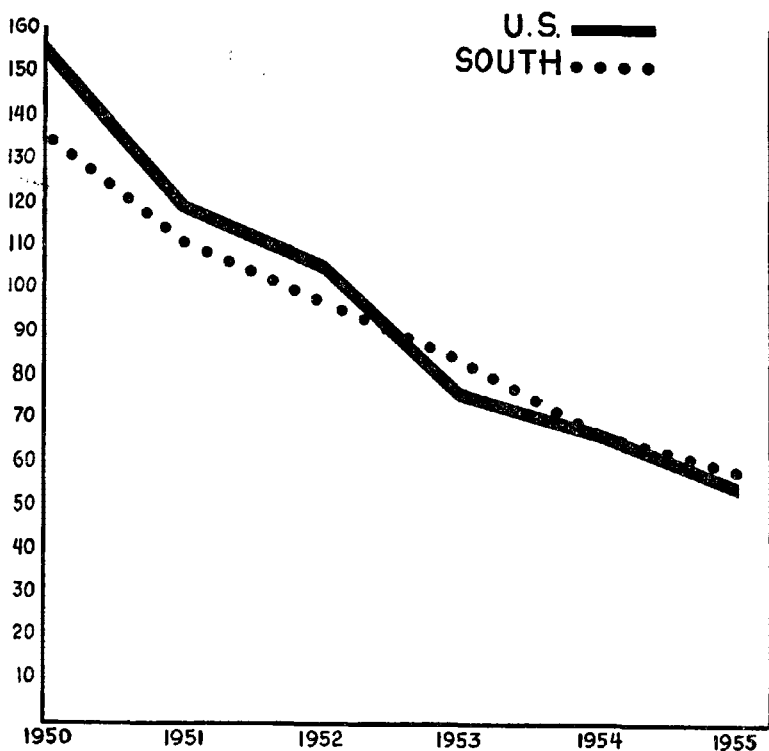
¹⁰ See "Teacher Supply and Demand Report," *The Journal of Teacher Education*, annually in March issues, and in connection with this discussion these issues for 1955 and 1956.

¹¹ Quoted in *Engineering & Scientific Manpower Newsletter*, No. 96 (July 12, 1956).

will increase approximately 50 per cent. A concurrent increase in the number of science and mathematics teachers will be necessary. Some rather crude estimates indicate that there will be an annual need in the South for between 2,500 and 4,000 new high school science and mathematics teachers. The demand for science and mathematics teachers in the South in 1955 was estimated to be about 3,000. This means that between 40 and 67 per cent of all the region's college graduates in mathematics and science in the next ten years will have to go into high school teaching to meet

FIGURE 3:

**SUPPLY OF SCIENCE TEACHERS
AS A PERCENTAGE OF DEMAND
FOR SCIENCE TEACHERS**



the demand. A 1951 study showed that only 10 per cent of the science graduates went directly into teaching.¹² It appears that it will be impossible to recruit the number of qualified science and mathematics teachers needed from the college graduates expected in the next few years. Other sources of science teacher supply must be found if the quality of science teaching is to be maintained.

Recent scattered data indicate some of the quality aspects of the science teacher problem. In the July 12, 1956, issue of *Engineering and Scientific Manpower Newsletter* is an item entitled "But Numbers Aren't Enough" which indicates the scores made on a basic general science test used by certain grammar schools in New York by college juniors and seniors preparing to teach. "The results were shocking," according to this account. "Whereas the average grade school student answered 85 per cent of the questions correctly in approximately 30 minutes, the average collegian was graded at 73 per cent after considering the test for one hour—with the book open!"¹³ A similar reaction is represented in this statement: "When our observer visited 60 classrooms to verify at first hand what the books and experts were saying about the deplorable state of mathematics teaching, he found 10 in which the teaching was reasonably effective; in the other 50 the instruction was so confused that learning of any kind seemed to be largely accidental. . . ."¹⁴

Even under the best conditions the number of people teaching science and mathematics without an adequate background will probably increase rapidly in the next few years. Therefore, programs for summer training and on-the-job training of science and mathematics teachers need to be greatly expanded. Steps to prepare adequately those who are now teaching will pay the most immediate dividends in the form of better prepared students.

In summary, the number of high school students taking science and mathematics will increase more rapidly in the immediate future than the number of qualified science and mathematics teachers. The problem will be rather to provide adequate courses,

¹² National Science Foundation, *Scientific Personnel Resources*, 17.

¹³ Cf. *Engineering & Scientific Manpower Newsletter*, No. 96 (July 12, 1956).

¹⁴ Henry S. Dyer, Robert Kalin and Frederick M. Lord, *Problems in Mathematical Education* (Princeton: Educational Testing Service, 1956), 17.

well taught, than to stimulate student interest, although these are closely related. Poor teaching can rapidly kill interest in a subject and in a career in science.

DEMAND FOR NUCLEAR SCIENTISTS

Most of the expanding demand for nuclear scientists in the next ten years will come from universities and industry rather than the government. The total number of additional professionally trained personnel who will be employed in 1965 is estimated to be between 15,000 and 25,000, only about 1,000 of whom will be additional AEC and AEC contractor employees.¹⁵ The McKinney Report comments: "Assuming the maximum growth figure is realized, almost 25,000 nuclear scientists and engineers will have to be trained before 1964. This indicates an annual net increase of 2,500. Inasmuch as we are now turning out personnel at the rate of 41,000 with bachelors', masters', and doctorates a year, we see that the nuclear field needs 6 per cent of our graduates over the next decade. This then is an imposing additional new competitor in the perennially short market supply of engineers and scientists."¹⁶

A recent survey of more immediate needs reports ". . . that in the next three years in the United States alone there will be an annual demand for approximately 2,000 engineers and scientists—mostly engineers—in the atomic power field. Of these 2,000 it is expected that approximately 1,200 will already be trained in nuclear technology. . . . Present nuclear educational and training programs of all types are geared to turn out fewer than 500 engineers and scientists annually. As a consequence, on the basis of the short range requirements alone, there is an immediate need to expand education and training capacity."¹⁷

The foregoing quotations indicate that there is great need to intensify the educational effort. Estimates of regional needs for personnel trained in nuclear fields have not been attempted be-

¹⁵ *Peaceful Uses of Atomic Energy*, II, 556.

¹⁶ *Ibid.*

¹⁷ *Major Activities in the Atomic Energy Program, July-December, 1955* (Washington: Government Printing Office, 1956), 55-56.

cause any such estimates would be bound to have a large margin of error. The field is so novel, so rich in activity and discovery, that its personnel needs are not safely calculable. But all signs indicate that overexpansion of nuclear educational programs is most unlikely; on the contrary, personnel shortages will almost certainly inhibit the rate of expansion to a more or less serious degree.

SKILLED MANPOWER NEEDED

Although the major emphasis of this section is on professional manpower needs in the nuclear energy field, there will be substantial needs for craftsmen and skilled technicians as well. They will substantially outnumber the professional personnel. In the McKinney Report summary of manpower requirements for nuclear power development, subprofessional workers outnumber the professional workers twelve to one.¹⁸ Not all these are skilled technicians by any means, but the McKinney Report points out that "there should be at least one, and more often several, semi-professional workers to each professional and degree-holding engineer."¹⁹

Skilled workers can greatly enhance the effectiveness of the professional engineer. Since they have a shorter period of formal training, new semiprofessional workers can be trained more rapidly than professional engineers and scientists. However, the schools and institutes for technician training lag behind the engineering schools in turning out graduates. In 1955, for example, there were less than 10,000 graduates of technical training programs, while there were more than 22,000 bachelor's degree graduates in engineering. The development of additional technical training programs in the region may be quite important to the future development of nuclear energy. A study of the present status and future needs of technical training programs was beyond the scope of the SREB project, but such a study might serve as a basis for deciding on technical education programs needed to assist the region's nuclear development.

¹⁸ *Peaceful Uses of Atomic Energy*, II, 547 (Table 5).

¹⁹ *Ibid.*, 526.

COLLEGE PROGRAMS IN SCIENCE AND ENGINEERING

It is impossible to separate nuclear science and engineering from the whole fabric of engineering and scientific education. It is therefore necessary to consider engineering, the physical sciences, and mathematics in examining the current status of nuclear educational programs in Southern colleges and universities. Educational problems as they relate to the life sciences, medicine, and agriculture are not considered here since they have been discussed in other chapters.

The South is not producing as many engineers in proportion to its college-age population as the nation as a whole. The data in Table 8 show the ratio of degrees earned in the region to the

TABLE 8
PERCENTAGE OF U. S. DEGREES IN SPECIFIED FIELDS
GRANTED BY SOUTHERN INSTITUTIONS

FIELD	1954			1955		
	Bachelor's	Master's	Doctor's	Bachelor's	Master's	Doctor's
<i>Engineering</i>	22	12	8	22	13	10
Chemical	22	19	17	25	19	24
Civil	25	12	7	23	14	—
Electrical	20	9	9	20	10	9
Industrial	24	7	17	26	9	11
Mechanical	20	13	7	20	13	10
Petroleum	69	65	—	73	70	—
<i>Physical Sciences</i>	25	21	15	26	19	14
Chemistry	26	23	18	28	19	15
Metallurgy	6	13	—	8	19	7
Physics	20	18	15	21	16	12
<i>Mathematics</i>	29	18	20	31	17	15
Percentage of U. S. College Age Popula- tion in the South	34			33		

Source: Mabel C. Rice and Neva A. Carlson, *Earned Degrees Conferred by Institutions of Higher Education, 1953-54, 1954-55*, Circulars No. 418, No. 461, Office of Education, U. S. Department of Health, Education, and Welfare (Washington: Government Printing Office, 1956).

national total. A marked deficiency appears in metallurgy, where the region is producing less than 10 per cent of the national total. A rough measure of the region's position relative to the nation is indicated by the fact that Southern institutions awarded about one-fourth of the B.S. degrees, while the region as a whole contains about one-third of the college-age population. Electrical engineering, mechanical engineering, and physics are somewhat below the regional average for science, engineering, and mathematics.

Southern institutions granted 22 per cent of the bachelor's degrees in engineering, but only 13 per cent of the master's degrees. In the physical sciences, these institutions granted 26 per cent of the bachelor's but only 19 per cent of the master's degrees. Significant differences between the numbers of B.S. and M.S. de-

TABLE 9

NUMBER OF ENGINEERING AND SCIENTIFIC DOCTORATES AWARDED
IN EACH SOUTHERN STATE IN 1954-55

State	Degrees Awarded
Alabama	4
Arkansas	6
Delaware	43
Florida	41
Georgia	20
Kentucky	23
Louisiana	29
Maryland	105
Mississippi	0
North Carolina	88
Oklahoma	30
South Carolina	1
Tennessee	45
Texas	125
Virginia	37
West Virginia	22
Total	619

Source: Mabel C. Rice and Nina A. Carlson, *Earned Degrees Conferred by Higher Educational Institutions, 1954-55*. U. S. Office of Education Circular No. 461 (Washington: Government Printing Office, 1956).

degrees awarded appear particularly in electrical engineering and industrial engineering, which show drops from 20 per cent at the B.S. level to 10 per cent at the M.S. level, and drops from 26 per cent for B.S. degrees to 9 for M.S. degrees, respectively, for these two fields.

At the doctoral level, Southern institutions show a marked decrease in productivity, also shown in Table 8. Southern universities granted less than 10 per cent of the engineering Ph.D.'s during the period 1950-55. In the physical sciences and mathematics the region granted only about 15 per cent of the doctorates during the same period. The one exception to this general poverty is chemical engineering, which remains relatively stable at about 22 per cent from the bachelor's through the doctorate level. In other fields the percentage of Ph.D.'s ranges from about 15 per cent downward.

The number of engineering and scientific doctorates awarded in each Southern state in 1954 and 1955 is shown in Table 9. The figures in the table clearly show that the distribution of earned Ph.D.'s among the states in the region is quite uneven. For instance, Maryland, North Carolina, and Texas produce more Ph.D.'s in science and engineering than all the remaining states together.

The problem appears to be less that of developing new programs than of expanding the enrollment in existing programs. Many of the doctoral programs have had few graduates. In engineering, forty-one of the forty-eight doctoral programs in the region have averaged less than two graduates per year during the past five years. In mathematics eleven of seventeen, in physics five of fifteen, and in chemistry nine of twenty-five doctoral programs have averaged less than two graduates per year during the same period. This suggests that there is a substantial potential for expansion of the existing doctoral programs in the region.

A background for nuclear science should also be integrated into the science programs of the liberal arts and education curricula. The extent to which this has been accomplished in the region has not been directly measured, but it is possible to draw some conclusions from a questionnaire sent to college presidents by the Southern Regional Education Board. Of the reporting in-

stitutions²⁰ giving no science or engineering degrees, only about 28 per cent offered one or more courses in nuclear science; that is, modern physics, introduction to nuclear physics, radiochemistry, and so forth. This suggests that a large number of colleges have not been keeping their course offerings in science up to date.

PLANNED PROGRAMS IN NUCLEAR SCIENCE AND ENGINEERING

Table 10 gives a synopsis of the planned programs in nuclear science and engineering of the colleges and universities in the region who cooperated in this study. The table lists all institutions giving graduate work in science and engineering and indicates roughly the status and plans of each. The term "program" in the tabulations refers to an organized sequence of courses that leads to a degree (B.S., M.S., or Ph.D.) in some branch of nuclear science or engineering. Of the fifty-six institutions listed in Table 10 which give graduate work in science and engineering, about 34 per cent have nuclear education programs and an additional 9 per cent are planning to start programs. About 80 per cent of the institutions listed offer one or more courses in some branch of nuclear science and engineering; 43 per cent have plans to add new courses. The eleven institutions offering no program and no courses also report, with only one exception, that they do not plan to add such courses.

It is encouraging to note that eleven of the sixteen states of the region now have institutions within their boundaries that offer one or more programs in nuclear science, and three of the remaining five states have institutions that plan to begin such programs.

EDUCATIONAL NEEDS IN NUCLEAR SCIENCE AND ENGINEERING

The interdependence of science and engineering is particularly evident in the nuclear field. The recent and rapid development

²⁰ The SREB questionnaire was sent to 176 colleges that do not grant degrees in science or engineering. Of these 153, or 87 per cent, responded and 110 indicated that they do not give any courses specifically in a branch of nuclear science.

TABLE 10

STATUS AND PLANS FOR EDUCATION IN NUCLEAR SCIENCE OF
SOUTHERN UNIVERSITIES

State and Institution	Have Program*	Plans to Initiate or Extend Program		Have Courses	Will Add Courses	Have No Courses
		Definite	Pre- liminary			
<i>Alabama</i>						
Alabama Polytechnic Institute				X	X	
Tuskegee Institute						X
University of Alabama	X			X		
<i>Arkansas</i>						
University of Arkansas	X			X	X	
<i>Delaware</i>						
University of Delaware				X	X	
<i>Florida</i>						
Florida State University	X	X		X		
University of Florida	X	X		X	X	
University of Miami				X		
<i>Georgia</i>						
Atlanta University						X
Emory University				X		
Georgia Institute of Technology	X	X		X	X	
University of Georgia	X			X	X	
<i>Kentucky</i>						
University of Kentucky			X	X	X	
University of Louisville			X	X	X	
<i>Louisiana</i>						
Louisiana State University	X	X		X	X	
Tulane University				X	X	
Xavier University						X
<i>Maryland</i>						
Johns Hopkins University	X			X		
University of Maryland	X			X	X	
<i>Mississippi</i>						
Mississippi State College				X		
University of Mississippi				X	X	
<i>North Carolina</i>						
Duke University	X			X		
University of North Carolina	X			X		
North Carolina State College	X			X	X	
<i>Oklahoma</i>						
Oklahoma A. & M. College	X			X		
University of Oklahoma	X			X	X	
University of Tulsa				X	X	

*Programs vary widely in scope.

TABLE 10 (Continued)

State and Institution	Have Program*	Plans to Initiate or Extend Program		Have Courses	Will Add Courses	Have No Courses
		Definite	Pre-liminary			
<i>South Carolina</i>						
Clemson Agricultural College			X	X	X	
South Carolina State College						X
University of South Carolina				X		
<i>Tennessee</i>						
Fisk University						X
George Peabody College						X
Tennessee A. & I. College			X	X		
University of Chattanooga				X		
University of Tennessee	X	X		X	X	
Vanderbilt University	X			X		
<i>Texas</i>						
Baylor University				X		
Hardin-Simmons University						X
Rice Institute	X			X		
Southern Methodist University	X			X		
Texas A. & M. College				X		
Midwestern University						X
South West Texas State Teachers College						X
Prairie View A. & M. College						X
Texas Christian University	X			X	X	
Texas College of A. & I.				X		
Texas Southern University					X	X
Texas Technological College			X	X	X	
University of Houston				X		
University of Texas	X			X	X	
<i>Virginia</i>						
University of Richmond				X		
University of Virginia	X			X	X	
Virginia State College				X	X	
Virginia Polytechnic Institute	X			X	X	
<i>West Virginia</i>						
West Virginia University		X				
Marshall College				X		

*Programs vary widely in scope.

of nuclear technology makes it necessary for the engineer to know more basic science than previously. Therefore, a broad educational program in science is essential to the development of a strong program in nuclear technology.

At the present time much more is known about education for nuclear science than about education for nuclear engineering, because of the parent-child relationship between these two fields. Nuclear science had to develop over almost four decades before nuclear engineering could begin to evolve as a separate specialty. Nuclear science had its beginnings over fifty years ago, but nuclear engineering began less than fifteen years ago. Because of this difference of age, attention is concentrated here on the educational needs of nuclear technology rather than of nuclear science.

Considerable attention has been given to the problem of nuclear science in engineering education and the training of engineers for work in nuclear technology. The American Society for Engineering Education, together with the American Institute of Physics and the National Science Foundation, sponsored a conference on Nuclear Science in Engineering Education in September, 1954. This conference, attended by leading authorities in nuclear science and engineering, unanimously adopted the following recommendations:

In view of the increasing role of atomic and nuclear phenomena in engineering, it is the sense of this conference that:

1. All *general physics* courses should give continual attention to the inclusion of modern physics material at appropriate places throughout the entire course.
2. All *engineering courses* should give continual and increasing attention to the inclusion of pertinent atomic energy material.
3. All *engineering curricula* should contain atomic and nuclear science material of a scope covered by a 3-semester-hour course at the junior or senior level (beyond general physics).
4. In view of the rapid advance of this new field it is also the sense of this conference that all *engineering schools* should give continual attention to the possibility and need for professional education in nuclear technology, especially at the graduate level.

The conference recognizes that the realization of these objectives will vary with local situations. It is evident, however, by the very nature of atomic energy that their implementation

can be achieved only through close cooperation of engineering and physics departments, as well as other science departments.²¹

The SREB Technical Panel on Manpower and Education gave consideration to this same problem and affirmed the conclusions given above. In addition the Technical Panel placed considerable emphasis on the need for more basic science and engineering and less specialized technical training in the engineering curriculum. The importance of teaching more basic science and mathematics, furthermore, has been cited recently in the Grinter Report,²² which considered all branches of engineering.

Both the SREB Technical Panel and the ASEE Conference recommended that specialized education for nuclear technology be conducted at the graduate level, after the student has received a thorough grounding in some established field of science or engineering. It should be emphasized that nuclear power requires almost all of the established technical fields, particularly mechanical engineering, chemical engineering, physics, and mathematics. One nuclear scientist and educator on the SREB technical panel on manpower and education put it this way, "The atomic field uses all the standard varieties of engineers. The new problems which these engineers face are associated with nuclear radiation. If the engineer understands these new problems, then he can take a position of leadership."

All engineers who work on reactor projects need a descriptive knowledge of nuclear concepts and a familiarity with nuclear terminology and processes. By no means all of them, however, need a quantitative, working knowledge of nuclear science and reactor technology. Educational programs in engineering need to take into account the requirements both for the specialists in nuclear technology and for the larger fraction of engineers who need only a general background in nuclear problems.

²¹ R. W. Houston, "Report of Summer Institute Preliminary Conference on Nuclear Physics in Engineering Education," *Journal of Engineering Education* XLIV (1954), 573.

²² L. E. Grinter, *et al.*, "Report of the Committee on Evaluation of Engineering Education," *Journal of Engineering Education* XLVI (1955), 26.

SPECIALIZED NUCLEAR FACILITIES FOR EDUCATION AND RESEARCH

The Southern region has a considerable inventory of nuclear facilities for education and research, and many new ones are being planned. As development proceeds it becomes increasingly important to explore the possibilities for future nuclear facilities and for regional cooperation in their planning and use. The existing ones are concentrated in the educational institutions of the region that offer graduate work in science and engineering, and in the national laboratories, particularly at the Oak Ridge National Laboratory. A survey of the nuclear facilities in Southern colleges and universities was included in the SREB questionnaire to college and university presidents. Each was asked to describe the facilities either now installed on the campus or planned for the future.

Thirty-two institutions reported some facilities for nuclear research. Among the thirty-two institutions listed, twenty-one (or 66 per cent) have radioisotope laboratories, and seven of these plan to expand their radioisotope laboratory facilities. Details are shown in Table 11. Four other institutions plan to establish radioisotope laboratories, and two more will add to their radioactive measuring and handling equipment. Thus about three-fourths of the institutions with special nuclear facilities can be expected to have radioisotope laboratories in the immediate future.

Seven Southern institutions report that they have accelerators of the Van de Graaff type. There are six accelerators of the Cockcroft-Walton type in the region, three of which belong to departments that have Van de Graaff accelerators as well. Furthermore, six institutions now have plans to obtain accelerators sometime in the future. If all these plans materialize the total number of institutions with accelerators will be raised to twelve (three of which would be added to existing accelerator facilities).

North Carolina State College is the only educational institution in the region that has a nuclear reactor facility. This was the first such facility in the United States. At the present time there are nine additional reactors in various stages of planning by Southern universities. One of these reactors is planned as a joint facility to

TABLE 11
SPECIAL NUCLEAR FACILITIES IN SOUTHERN UNIVERSITIES,
BOTH EXISTING AND PLANNED

Institution	Present Facilities	Planned Facilities
<i>Alabama</i> *Alabama Polytechnic Institute	Radioisotope measuring & handling equipment	Subcritical assembly, expansion of radioisotope facilities, and perhaps a reactor
*Tuskegee Institute *University of Alabama	Radioisotope lab facilities Radioisotope measuring and handling equipment	Hope to add a particle accelerator
<i>Arkansas</i> *University of Arkansas	Radioisotope lab facilities, mass spectrometers	Cockcroft-Walton accelerator (400kv), subcritical assembly, indefinite plans for a reactor
<i>Delaware</i> University of Delaware	None	Reactor simulator
<i>Florida</i> *Florida State University	Radioisotope lab facilities, Cockcroft-Walton accelerator, Cobalt 60 gamma source	Van de Graaff accelerator, beta-ray spectrometer, & expanded radioisotope lab facilities
*University of Florida	Radioisotope lab facilities, Van de Graaff accelerator	Research-power reactor, subcritical assembly, Cobalt-60 gamma source, a linear accelerator
University of Miami	Radioisotope lab facilities	Possibly a reactor
<i>Georgia</i> Atlanta University	Radioactive measuring equipment Radioisotope lab facilities	Enlarged radioisotope facilities None
*Emory University *Georgia Institute of Technology	Radioactive measurements lab, equipment for nuclear spectroscopy	Radioisotope lab, subcritical assembly; probable additions, research reactor and accelerator
*University of Georgia	Radioisotope measuring facilities	Radioisotope lab
<i>Kentucky</i> *University of Louisville	Radioisotope lab facilities, mass spectrograph	Hope to enlarge radioisotope facilities & add a small reactor
<i>Louisiana</i> *Louisiana State University	Radioisotope lab facilities, (100kv) Cockcroft-Walton accelerator, Van de Graaff accelerator (1 Mev) and associated equipment, and a beta ray spectrometer	Expanded radioisotope facilities
*Tulane University	Radioisotope lab facilities, mass spectrometers, and a beta ray spectrometer	Cloud chamber under construction

*Member Oak Ridge Institute of Nuclear Studies.

TABLE 11 (Continued)

Institution	Present Facilities	Planned Facilities
<i>Maryland</i>		
Johns Hopkins University	Accelerator (1 Mev)	—————
*University of Maryland	Radioisotope lab facilities	Subcritical assembly, studying needs for a research reactor
<i>Mississippi</i>		
*University of Mississippi	Facilities for radioactive measurements	Analog computer for nuclear problems under construction
<i>North Carolina</i>		
*Duke University	Van de Graaff accelerator (4 Mev)	—————
*University of North Carolina	Radioisotope lab facilities	None
*North Carolina State College	Research reactor (10 KW), neutron source, and radioisotope lab facilities	Subcritical assembly, reactor modifications to obtain neutron-free gamma ray source
<i>Oklahoma</i>		
Oklahoma A. & M. College	Radioisotope lab facilities	X-ray equipment, cobalt gamma ray source
*University of Oklahoma	Facilities for radioactive measurements	—————
<i>South Carolina</i>		
*Clemson Agricultural College	Radioisotope lab facilities	—————
*University of South Carolina	Radioisotope lab facilities	Perhaps a subcritical assembly
<i>Tennessee</i>		
Tennessee A. & I. State University	Radioisotope lab facilities	—————
*University of Tennessee	—————	—————
*Vanderbilt University	Radioisotope lab facilities, neutron source, alpha-, beta-, gamma-, and neutron- spectrometers, X-ray equipment, Cockcroft-Walton accelerator	Central radioisotope lab, subcritical assembly, reactor simulator, research reactor
<i>Texas</i>		
*Rice Institute	Van de Graaff accelerators (6 Mev and 2 Mev), Cockcroft-Walton accelerator (200 kev), and radioisotope lab facilities	Considering research reactor (in collaboration with Univ. of Texas, Texas A. & M. and the Welch Foundation)
*Texas A. & M. College	Cockcroft-Walton accelerator, and radioisotope lab facilities	(reactor, see above)
Texas Southern University	None	Radioisotope lab facilities
University of Houston	None	200 kev Deuteron accelerator

*Member Oak Ridge Institute of Nuclear Studies.

TABLE 11 (Continued)

Institution	Present Facilities	Planned Facilities
*University of Texas	Van de Graaff accelerator, Cockcroft-Walton accelerator, and radioisotope lab facilities	Subcritical assembly (reactor see Rice Inst.)
<i>Virginia</i> *University of Virginia	Reactor simulator, two Van de Graaff accelerators, radioactive measuring equipment	Research reactor
*Virginia Polytechnic Institute	Van de Graaff accelerator (2 Mev), reactor simulator, & bubble chamber	Radioisotope lab facilities, beta and gamma spectrometers
<i>West Virginia</i> West Virginia University	Radioisotope lab facilities	Enlarged radioisotope facilities

*Member Oak Ridge Institute of Nuclear Studies.

serve three institutions. It should be noted, however, that all these plans are not likely to be fulfilled in the immediate future.

The survey also shows that nine of the thirty-six schools listed in Table 11 have plans to acquire a subcritical assembly. This type of nuclear facility has many attractive features for training students, and additional institutions will probably include one in their planning.

Table 11 also indicates that about 75 per cent of the institutions with facilities are members of the Oak Ridge Institute of Nuclear Studies (ORINS). This organization has played a key role in the development of nuclear programs in the region, and it deserves credit for the rapid advancement of many Southern schools in the nuclear field. By means of the ORINS Research Participation Program, faculty members have access to many of the vast facilities at Oak Ridge. This program has permitted many faculty members to learn and keep abreast of the new and rapidly developing nuclear field. Through the ORINS Graduate Fellowship Program, graduate students from member institutions can also come to Oak Ridge to use its facilities in their thesis research.

As more institutions develop an interest in the nuclear field, ORINS will undoubtedly continue to be of very great assistance,

but facilities at Oak Ridge will always be something quite different from facilities on the campus. In view of the critical shortages of personnel discussed previously, there is need to expand the facilities at universities which can contribute most directly to the education of students.

EDUCATIONAL FACILITIES NEEDED IN NUCLEAR SCIENCE AND ENGINEERING

In considering the facilities needed at a given school it is necessary to distinguish between facilities primarily for research and facilities primarily for laboratory course work. By *course-work facilities* are meant nuclear facilities used by all students in particular laboratory courses, while *research facilities* refer to facilities used for faculty and thesis research. Generally, research facilities cost far more than course facilities. As a further generalization, one can say that course work facilities of certain types are needed by every institution with a program in the nuclear field. This means that the requirements for course work facilities are determined by the curriculum. On the other hand, the research facilities at a given institution are determined by the interests of its faculty members and the research aims of the institution. From a regional point of view, the research facilities are of primary concern because they are an indispensable prerequisite for progress in nuclear science and engineering research in the South.

At least for the immediate future, the principal nuclear facilities needed for programs in science and engineering are radioisotopes laboratories, particle accelerators, nuclear reactors, and subcritical assemblies. Nuclear facilities may be classified as follows with respect to use in universities:

<i>Facility</i>	<i>Classification</i>
Subcritical Assemblies	Course Work
Radioisotope Laboratories	Course Work or Research
Particle Accelerators	Research
Nuclear Reactors	Research

The particular value of each of these facilities to various university departments, the cost range of the facilities, and their

importance to the region will be discussed in the sections which follow.

In almost every field of science and engineering the use of radioisotopes gives clear promise of great advances. The applications of radioisotopes are by no means restricted to the physical sciences and engineering. As earlier chapters of this book have shown, agriculture, medicine, biology, and other fields may eventually find the use of radioisotopes as common and as important as the use of the microscope. Thus, of all the nuclear facilities, radioisotopes facilities will be needed in the greatest number and can be used in the most diverse fields. As facilities for course work they will be needed in almost all colleges and universities. Fortunately the cost of radioisotopes facilities is small in comparison with that of accelerators, reactors, and other more specialized nuclear apparatus. Course-work facilities can be set up in existing buildings with only minor modifications.

As an example of a radioisotopes laboratory for course work, one may consider that at Rutgers University. It was designed primarily for training purposes and was completed early in 1955. The laboratory was constructed by altering three rooms in an existing building. According to the head of the physics department, the total cost of the alterations, the necessary equipment and supplies, and salaries for the first semester of operation came to a total of \$23,026. The costs of giving the radioisotopes laboratory course during two semesters amount to about \$900 for supplies plus the salaries of two instructors, one from Chemistry and one from Physics, and a graduate assistant. In general, this facility has been limited to teaching, although some use of the equipment for research has been permitted, short of interfering with the teaching function.

The radioisotopes laboratory at the Georgia Institute of Technology is an example of a facility for both education and research. In April, 1956, Governor Marvin S. Griffin of Georgia made available \$300,000 for the construction and equipment of this laboratory, which is in the final phase of design.²³ It will include two

²³ Equipment specifications and the general floor plan are given in "Radioisotopes Laboratory, Plan and Cost Estimates," Interim Report by the Radioisotopes Laboratory Planning Committee, Georgia Institute of Technology, Atlanta, Georgia, September, 1956 (Unpublished).

large laboratory spaces, one for instruction in radiochemistry and the other for physics instruction with a subcritical assembly. Three smaller laboratory spaces are being provided for research. Office space, an instrument shop, and a counting room will also be provided in the same building. The equipment cost for the entire laboratory will be about \$35,000, excluding the subcritical assembly. The remaining funds will cover the capital costs of the building plus about \$5,000 for the subcritical assembly.

The costs of the two facilities mentioned here agree reasonably well with the independent estimates of Myers.²⁴ The study prepared by Myers and a more detailed study of design requirements for radioisotope laboratories prepared by Ward²⁵ are excellent references for groups engaged in the planning of such facilities.

A broad range of research programs involving the use of radioisotopes in medicine, the life sciences, the physical sciences, and engineering should pay dividends in the economic and social development of the South. New techniques in the treatment of disease, in industry, and in agriculture are just now developing, and there is a clear opportunity for the South to take the lead. In achieving this goal it is most important that the colleges and universities cooperate and avoid, wherever possible, the duplication of expensive research facilities. A broad range of education programs using radioisotope facilities for course work is also a necessity. In facilities of this type duplication is unavoidable and even necessary to permit an increasing number of schools to develop laboratory courses involving the handling and use of radioisotopes.

In comparison with radioisotopes laboratories, particle accelerators play a more specialized role. Historically accelerators have been the research tools of nuclear physics. They have made possible a detailed study of the structure of nuclei and the nature of nuclear reactions. Such studies have been and will continue to be fundamental to the advancement of nuclear science and technology. Basically, accelerators are devices for producing a beam of particles at precisely controlled energies with comparatively low

²⁴ F. E. Myers, "Suggested Programs and Cost Estimates for Instruction in Nuclear Science and Engineering," Argonne National Laboratory Report, 1955 (Unpublished).

²⁵ D. R. Ward, *Design of Laboratories of Safe Use of Radioisotopes*, AEC Document AECU-2226.

intensities or in the form of periodic bursts. The beam of particles may consist of electrons, protons, or the nuclei of heavier atoms. These beams may be used directly to bombard various targets, or they may produce, in turn, beams of neutrons or gamma rays. Very high energy accelerators like those at the University of California Radiation Laboratory and at the Brookhaven National Laboratory are capable of producing the new types of fundamental particles such as mesons and positrons which are now of great interest to physicists.

The majority of accelerator studies are concerned with a determination of the behavior of nuclei, that is, with basic and applied nuclear physics. However, the beams of particles produced by accelerators with sufficient energy (that is, capable of producing external beams of approximately 10 Mev protons, 20 Mev deuterons, and 40 Mev alpha particles) have proved exceptionally well fitted for producing radioisotopes of all types. In this role an accelerator could give excellent support to radioisotope facilities. Accelerators may also be used as radiation sources for the study of radiation effects on various materials.

The costs of particle accelerators depend on the type of particle to be accelerated and the energy desired. Electron accelerators are comparatively less versatile and much less expensive for a given energy. Accelerators for protons and heavier particles usually range in cost from about \$100,000 for the low energy machines which require no special building (for example, the 2-mv Van de Graaff or a small cyclotron producing 3 Mev protons) to roughly \$750,000 for higher energy machines which require a special building in addition to the capital cost of the machine. The 6-mv Van de Graaff and cyclotron capable of producing 15 Mev protons are examples of the higher energy machines. These higher energy accelerators require a special staff for operation and maintenance, and the annual operating cost is considerable, very roughly of the order of one-tenth the capital investment in the machine.

The very high energy machines are roughly in the ten-million-dollar range and are correspondingly much more expensive to operate. There is considerable national interest in these machines, however, and the possibilities of federal support for a regional facility are quite good.

Clearly only institutions with a well-developed program of graduate study and research are in a position to consider expensive accelerator facilities. As more institutions in the South develop this competence, the value of cooperation will become increasingly clear. Needless duplication of accelerator facilities and the failure of facilities to pay off in good research must be avoided if the South is to develop soundly in the nuclear field.

Nuclear reactors are research facilities comparable with the higher energy accelerators. They are not necessary for course work because of the lower cost and better suitability of the subcritical assemblies and reactor simulators for student laboratories. However, as a research facility they can be extremely valuable. In contrast with accelerators, a reactor primarily produces neutrons, but it produces them at a steady rate and in great quantity. Thus the reactor is not a unique instrument for producing neutrons, but it does have the edge in rate of production and beam intensity.

Reactors are particularly valuable in the study of radiation effect on materials, in the production of radioisotopes, and in studies of the structure of solid matter (provided the neutron flux is sufficiently high). In almost all research applications the potential value of a reactor increases very rapidly with the neutron flux. Unfortunately the capital and operating costs increase at about the same rate as the research potential. An excellent summary of reactor types, their relative cost, versatility, and safety has been given by Benedict.²⁶

A small reactor of the swimming-pool or water-boiler type costs roughly \$150,000. A special building and operating staff will be required in addition. The annual operating cost including salaries will probably exceed 10 per cent of this figure. A high-flux tank-type reactor without the necessary special research facilities and building will cost about ten times this figure with a corresponding increase in annual operating expense. Thus reactors like accelerators require a sizable capital investment and continuing support at a high level.

The success of reactor facilities and their value to the development of the region will depend critically on regional cooperation.

²⁶ Manson Benedict, "Nuclear Reactors for Research," *Chemical Engineering Progress*, Vol. 51 (February, 1955), 65.

The region does not need a high-flux research reactor in every state,²⁷ but through cooperation every Southern state can profit from a smaller number of truly first-rate facilities in the region.

The subcritical assembly is particularly valuable for nuclear engineering education because it can be used to illustrate many important aspects of a full-scale reactor. It is simple and safe so that students may work directly with it to perform a number of student-laboratory experiments. As a teaching aid it has many advantages over a research reactor in illustrating general principles. Furthermore the Atomic Energy Commission will now make available the necessary uranium (about \$100,000 worth) on loan to educational institutions who satisfy certain reasonable requirements. The AEC will also make available a neutron source to activate the assembly. The institution must pay the handling, packing, and transportation costs, and it must assume liability for loss of any of the uranium. The probable cost²⁸ of a subcritical assembly to an institution will be about \$5,000. No special building is required.

This arrangement for obtaining a subcritical assembly at a small fraction of its actual cost should be an enormous benefit to engineering schools in the region. Educational institutions should also consider the "argonaut," a zero-power ("naut"-power) reactor designed at Argonne National Laboratory.²⁹

Some other facilities may also be valuable. For example, simple and inexpensive reactor simulators may be constructed on the campus for educational purposes or more elaborate and expensive simulators may be purchased. Engineering departments can construct facilities for the study of many special reactor problems without a reactor. Problems in heat transfer, metallurgy, and chemical separation immediately come to mind in this connection. Many other examples of this type have been noted by Isbin in his excellent "Survey of Nuclear Engineering Research."³⁰

²⁷ This conclusion is supported by the discussions of the Technical Panel on Manpower and Education held in Atlanta, Georgia, on May 21-22, 1956, as a part of the regional Nuclear Energy Project. One expert estimated the number of reactors needed by universities in the region as seven or less.

²⁸ This and other data provided by Prof. Lyle Borst, New York University.

²⁹ D. H. Lennox and B. I. Spinrad, *Interim Report on "Argonaut,"* Argonne National Laboratory Report 5552, March, 1956.

³⁰ H. S. Isbin, *Journal of Engineering Education* XLVI (September, 1955), 76-79.

PROPOSED REGIONAL AND STATE ACTION

On the basis of the considerations presented in this chapter, the SREB Work Conference took the position that the training of nuclear scientists is the key to the development of nuclear industry within the region. The Conference recognized that many of the universities in the South are planning to expand training and research in nuclear science and technology. Some of these programs will require research facilities which are extremely expensive to construct and operate. The Work Conference believed that through cooperative planning on a regional basis the universities might better prepare to meet the region's needs and at the same time avoid unnecessary duplication. It was also the judgment of the Work Conference that the agencies in the region interested in training and research in nuclear science, including the Oak Ridge Institute of Nuclear Studies and the Southern Regional Education Board, should coordinate their efforts. The Work Conference was particularly concerned that the need for technical or skilled manpower, at a subprofessional level, should not be overlooked in regional planning.

Accordingly, the Work Conference recommended that the Southern governors establish a regional advisory committee, with the Southern Regional Education Board as secretariat, to assist educational institutions in developing education and research in nuclear science. The advisory committee would study the possibility of regional cooperation in the development and use of centers for highly specialized instruction and research. It would also try to make new arrangements with the Oak Ridge Institute of Nuclear Studies and other agencies for more effective, region-wide use of their facilities. Finally, the advisory committee would investigate the possibilities of expanding training programs for technicians needed in nuclear enterprises.

While the regional advisory committee works at the coordination of the efforts of federal, state, and private institutions, the Work Conference felt that many intra-state activities should be undertaken in order to develop the manpower needed for nuclear industry and the application of radiation. Chief among these should be a program designed to increase the number and im-

prove the training of high school teachers of mathematics and science. The Work Conference was impressed with the probability that the demand for new science and mathematics teachers will be about four times as great as the supply during the coming decade. If the shortage is to be overcome, immediate, organized attention to the problems involved will be required in each of the Southern states. The Work Conference recommended that the states offer whatever incentives may be necessary to obtain and hold competent teachers of science and mathematics in high schools. Sounder science and mathematics curricula should be required in high schools, and high school students should be motivated to enter science professionally by means of vocational guidance and by creating additional science scholarships in state colleges.

So concerned was the Work Conference to promote science and mathematics in the high schools that it recommended that the governor of each state consider appointing a commission on high school science and mathematics to improve instruction and encourage more students to consider careers in these fields and in engineering. It suggested that such commissions be made up of representatives of education from all levels—industry, agriculture, the legislatures, organizations of parents, and other appropriate groups. The recommended state commissions would explore all possible sources of trained personnel now available, such as retired military personnel, married women, and persons borrowed from industry, who might be persuaded to teach science and mathematics and relieve the current shortage. They would make arrangements to discover and guide gifted high school pupils and encourage high school seniors to prepare for careers as teachers of high school science and mathematics. In addition, the proposed commissions would develop state-wide in-service training to improve the qualifications of science and mathematics teachers and enable teachers in other subjects to qualify themselves to teach science and mathematics.

Turning to the colleges and universities of the region, the SREB Work Conference recommended that the governors urge the appropriate officials in their several states to strengthen and expand undergraduate and graduate education and research in science and engineering. In order to do this, the Work Confer-

ence thought it would be necessary, to begin with, to provide competitive salaries for Southern college and university faculties, establish attractive fellowships to support capable graduate students, and install medium- and low-cost nuclear research and teaching facilities, such as radioisotope laboratories and subcritical assemblies. Inadequate programs of higher education and research are regarded as the most critical obstacle in the way of nucleonic development. Progress in these critical areas will certainly be slow so long as the salary scales of Southern universities remain significantly lower than those offered by Northern, Eastern, or Western universities, by government, or by industry.

In addition to competitive salaries, Southern universities must maintain a climate conducive to scholarly performance. Funds and facilities required for creative research are essential. The Work Conference thought that nuclear science and engineering curricula throughout the region should fulfil all standards established by the appropriate national accrediting agencies. Four-year scholarship programs to support promising high school graduates in the study of mathematics, science, and engineering should be provided in each state. The Work Conference suggested that one scholarship for each 20,000 citizens would be a realistic goal. It was even more concerned that graduate fellowships in science and engineering be provided, for Southern programs are least developed at the graduate level from which the most highly trained men and the new teachers needed by the colleges may be drawn.

The Work Conference felt that organized effort to improve high school science and mathematics should be matched on the college and university level. It recommended, therefore, that the governors establish advisory commissions to deal with mathematics, science, agriculture, and engineering education as related to nuclear development. These commissions would work closely with the regional committee which the Work Conference proposed and thus complete the regionwide organization designed to promote the South to leadership in the nuclear era.

ROSTER OF PARTICIPANTS, SOUTHERN REGIONAL EDUCATION BOARD PROJECT ON NUCLEAR ENERGY, 1956

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University of Alabama

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Auburn Research Foundation
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Department of Radiology
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Department of Agronomy
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University of Kentucky

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Physics, Louisiana State University

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Physics Department, Louisiana
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Division of Reactor Development
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Division of Analytical and Physical Chemistry
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Halifax District Hospital
Daytona Beach, Florida
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Engineering Development Branch
Division of Reactor Development
U. S. Atomic Energy Commission
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South Carolina State Board of Health

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Clinical Radioisotopes Center
Vanderbilt University Hospital

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Bowman Gray School of Medicine
Department of Radiology
Winston-Salem, North Carolina

CLINTON C. POWELL, *Special Assistant for Radiological Health*

U. S. Public Health Service
Washington, D. C.

D. P. ROBERTS, *Chief Engineer*

Industrial Hygiene Service
Tennessee Department of Public Health
Nashville, Tennessee

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Houston, Texas

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Rutgers University
Newark, New Jersey

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Radiological Health
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Cincinnati, Ohio

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Department of Radio-Pharmaceuticals

Abbott Laboratories
North Chicago, Illinois

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National Bureau of Standards
U. S. Department of Commerce

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Nuclear Energy Committee
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News Department

WTVT Television

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 Governor's Office
 Tallahassee, Florida

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Radiological Health Branch
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School of Arts and Sciences
Florida State University
- CHARLES ROBBINS, *Executive Manager*
Atomic Industrial Forum
New York, New York
- G. O. ROBINSON
Savannah River Plant
U. S. Atomic Energy Commission
Aiken, South Carolina
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Florida State University
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THE AUTHOR—

Redding Sugg, Jr., is a consultant to the Regional Education Board and is also a member of the faculty of the Georgia State College of Business Administration in Atlanta.

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